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A CLOSER LOOK:

Machine Learning-Based Clssification of Variable Stars

pg. 8

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On behalf of the 2025–2026 editorial staff, we are honored to present the 24th volume of the Texas Undergraduate Research Journal (URJ). Since its founding, URJ has been dedicated to promoting undergraduate excellence, encouraging students to pursue scholarship and creativity through research. Our mission to highlight undergraduate research and make it accessible across disciplines culminates in the publication of our annual journal.

In addition to the journal, URJ co-leads the Capital of Texas Undergraduate Research Conference (CTURC) and hosts free events that help undergraduates immerse themselves in the research community at the University of Texas at Austin.

The 2025–2026 academic year presented challenges, particularly with changes in funding. Nevertheless, our members and authors prevailed, creating a beautiful volume that brings URJ's purpose to life. We extend our heartfelt thanks to our members, who spent countless hours—in and out of meetings—editing manuscripts, formatting content, and dedicating many evenings to elevating undergraduate research.

Finally, we want to thank our Volume 24 authors. It has been a privilege to work with some of the brightest minds of our generation, and we could not have produced this journal without your hard work and persistence. We have no doubt that each of you has a bright future ahead—one where you will continue to improve the world and champion research for generations to come.

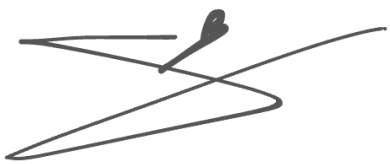
We at URJ hope you enjoy reading this year's outstanding work and encourage you to explore past volumes and Pioneer articles written by our editorial board to see how undergraduates are making a lasting impact.

Sincerely,

Siddhartha Shah & Sifallah Bouyadjera

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Table of Contents

Life, Liberty, and the Pursuit of Property: Comparing Locke's and Rousseau's Ideas of Private Property

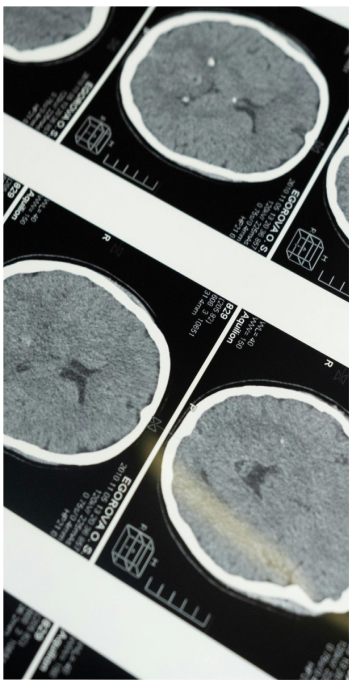
Tanvi Gupta



Government 8

Automated Hepatic Vein Segmentation and Attenuation Measurement in Contrast-Enhanced CT Scans: A Reliable Alogorithmic Approach

Ash-Hur Ahmad
Dr. Moiz Ahmad, PhD



Medicine 25

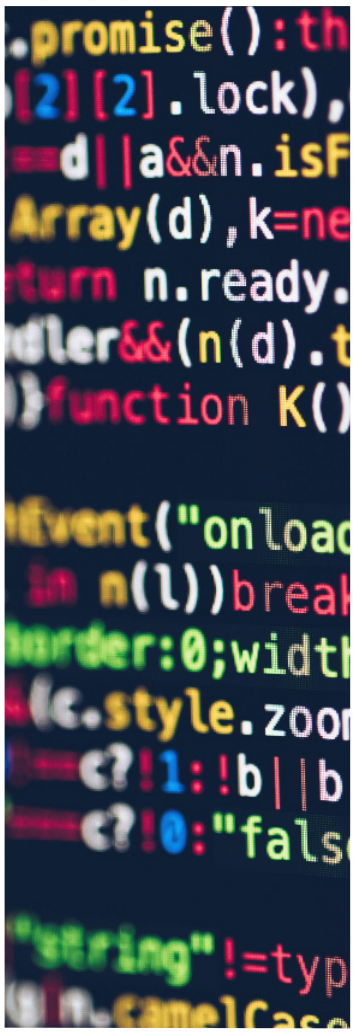
Cultural Perceptions of Emerging Technologies: Investigating Biosensor Adoption Among South Asians with Type-2 Diabetes

Anagha Joby



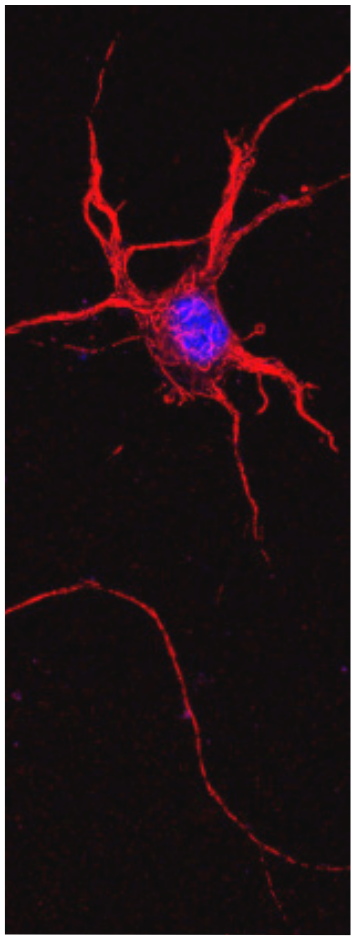
Classification of Variable Stars Using Machine Learning Models

Riya Addula
Alaina Gomez
Juhi Malwade



Identification and Validation of CHD1L's Partners During Neurodevelopment

Susannah Lynn-Macrae



Physics and Astronomy 42
Neuroscience 45

Life, Liberty, and the Pursuit of Property: Comparing Locke's and Rousseaus' Ideas of Private Property

Tanvi Gupta
The University of Texas at Austin

INTRODUCTION

The intellectual legacies of John Locke and Jean-Jacques Rousseau form a cornerstone of modern political philosophy. Their writings, particularly Locke's Second Treatise of Government and Rousseau's Discourse on the Origin and Basis of Inequality Among Men, grapple with questions about the nature of property, governance, and social inequality. In his work, John Locke focuses on how property is a natural right that contributes to the foundation of government and progress, while Rousseau argues that property and its acquisition is an artificial construct leading to inequality and the eventual collapse of society. Both philosophers sought to understand and critique their time's social and political structures, which they viewed as products of the Enlightenment, offering insights that resonate with contemporary debates on justice, wealth inequality, and human rights. This comparison of Locke and Rousseau is essential for exploring the philosophical foundations of civil society and the ideological tensions that underpin modern governance. The concept of private property lies at the heart of Locke and Rousseau's political theories, yet their perspectives diverge significantly. Locke frames property as a natural right derived from labor, which serves as a foundation for individual freedom and societal progress.

In contrast, Rousseau critiques property as the origin of social inequality and moral corruption, suggesting that it transforms human relations into hierarchies of power and competition. Both thinkers employ the "state of nature" as a hypothetical framework to investigate the origins and implications of property; however, their differing assumptions about human nature and the purpose of political society lead to vastly different conclusions. This difference reflects their philosophical priorities and underscores the broader ideological conflicts of their time, between individualism and collectivism, progress and morality, and liberty and equality.

This paper is organized into three main sections. The first examines Locke's conception of property as a natural right within the state of nature, emphasizing his labor theory of value and its implications for the legitimacy of government. The second explores Rousseau's critique of property as a socially constructed institution, tracing its origins and consequences in developing inequality. The final section compares and contrasts their views, analyzing points of convergence, such as their shared recognition of property's transformative power and their fundamental disagreements over its moral and political significance.

This analysis aims to highlight the significance of Locke and Rousseau in shaping modern political thought. Locke's optimistic vision of property as a foundation for liberty and progress contrasts sharply with Rousseau's critique of property as a source of inequality and societal decay. However, both thinkers contribute to an ongoing dialogue about the nature of justice, the role of government, and the ethical implications of wealth and power. By situating Locke and Rousseau in conversation with one another, we gain a deeper understanding of the philosophical roots of modern society and the enduring tensions that continue to shape debates about property, governance, and social inequality.

JOHN LOCKE

The State of Nature and the Foundation of Property

Locke provides a comprehensive account of political obligation and authority and the limitations of governmental

power in his Second Treatise of Government. By grounding property in labor and self-ownership, Locke offers a framework that continues to shape modern discussions about individual rights, economics, and political legitimacy. Locke begins his Second Treatise by describing the state of nature as a condition of equality and freedom. He asserts that all individuals are born with the same natural rights, bound by reason, which teaches them not to harm others in their "life, the liberty, health, limb, or goods of another" (§6). This foundational idea ties property to natural law, suggesting that ownership extends the natural rights to life and liberty, the very idea of ownership is integral to the foundation of democratic government, a concept that Lcoke assumes is given and is never fought against. In the state of nature, Locke posits that resources are common and available to all but must be appropriated through labor to become private property. This sets up his labor theory of property, emphasizing the moral and practical legitimacy of ownership derived from individual effort.

He begins Chapter II by urging his reader to "consider what state all men are naturally in," referring to the state of nature (§4). Locke's state of nature is not merely a theoretical construct but also a critique of absolutist governments, specifically the Stuart Monarch's theory of the divine right of kings (the predominant English theory of government post-restoration) which he viewed as violating natural law. Locke emphasizes that natural rights are gifts from God, inherent to each person and undiminished until one enters society. He argues that all individuals are bound by the duties defined by the law of nature, which he asserts is eternal and immutable. By grounding his theory of property in the natural rights framework, Locke establishes a moral and rational basis for ownership that transcends the arbitrary decrees of rulers. He suggests that the moral condition of people in this state is fundamentally optimistic, with each person born endowed with a set of rights that they retain until they consent to enter civil society, at which point some rights may be surrendered.

In Locke's vision, the state of nature is characterized by a community of individuals living under natural law. The transition from this state occurs when individuals establish a "judge on earth with authority to determine all the controversies" (§89). Locke emphasizes that this judge must be impartial and administer the law fairly to maintain legal order. Individuals exist in a state of nature when these criteria are not met. Locke argues that humans are not inherently inclined toward conflict with one another; instead, when individuals ignore the law, it leads to violent discord. Locke's characterization of the state of nature is built upon two fundamental aims:

1) to elucidate the origins of political society

2) to examine the rise and scope of legitimate authority within that society

In Locke's framework, the state of nature is less about historical reality and more a relational concept that delineates moral obligations and rights between individuals who have not consented to submit their disputes to a legitimate government. Therefore, the state of nature is not confined to a specific geographical territory where government control is absent; instead, it describes moral relationships among individuals. Within this framework, the state of nature is a condition of uncertain peace, where individuals may attempt to follow the law of nature but often fail to do so.

Locke's vision of the state of nature also underscores his optimistic view of human nature. Property emerges as a practical necessity, enabling individuals to sustain themselves and secure their independence. However, Locke also acknowledges the potential for conflict, particularly as resources become scarce or individuals seek to accumulate beyond their needs. These tensions necessitate the formation of the government to regulate property and resolve disputes, thereby bridging the gap between the state of nature and civil society. Despite these variations, Locke identifies a common social problem that permeates all forms of the state of nature: the absence of a reliable judge with the authority to resolve disputes. Without such a figure, individuals risk becoming partial or vengeful in executing their natural rights, leading to feuds, conflicts, and wars (§16). This pervasive insecurity and the potential for violent conflict are primary motivations for individuals seeking the protection a civil government offers.

Locke asserts that property originates from the natural right of self-ownership. He writes, "Yet every man has a property of his own person; this nobody has any right

to but himself. The labor of his body and the work of his hands we say are properly his" (§27). Locke establishes the foundational principle that individuals inherently own themselves, and this self-ownership extends to the products of their labor. Locke's focus on labor as the basis of property also reflects his broader view of human purpose. Individuals sustain themselves and contribute to the collective good by transforming the natural world through labor.

Natural Limits to Property

Locke recognizes the potential for abuse in accumulating property and imposes natural limits on its accumulation. He goes on to define three critical restrictions on the accumulation of property in the state of nature (§31-7):

1. Use Before Spoiling: Individuals may only appropriate as much as they can effectively use before it spoils. This principle ensures that resources are not hoarded or wasted, reflecting a concern for individual and communal well-being.

2. Sufficiency for Others: One must leave enough for others. This stipulation emphasizes equity, ensuring that the appropriation of resources does not infringe upon the rights and needs of others within the community.

3. Labor as Justification: Property rights can only be acquired through one's labor. This idea reinforces that ownership is grounded in personal effort and investment, linking individual rights to productive contribution.

Together, these restrictions underscore Locke's commitment to a balanced and fair system of property ownership, aiming to harmonize individual rights with the collective good. By establishing these principles, Locke seeks to foster a civil society that respects natural law while upholding personal autonomy, thereby creating a framework for legitimate governance that is both practical and philosophically robust.

The first limitation of Locke's property theory becomes somewhat moot when we consider the role of money, which allows for the storage of value that does not decay over time. With the introduction of money, people can accumulate wealth without the immediate constraints of physical goods, fundamentally altering the dynamics of property ownership. The second limitation arises when we recognize that those lacking land access can still acquire material goods through alternative means. This creates a scenario where inequality can persist even among those who do not own land, as some may become skilled at developing or producing goods that can generate wealth. The third limitation is significant; Locke acknowledges that property can be alienated, meaning individuals can transfer property ownership to others

The invention of money, Locke acknowledges, disrupts the natural limits on property. He observes, "It is plain that men have agreed to a disproportionate and unequal position of the earth" (§50). Unlike perishable goods, money enables individuals to accumulate property beyond what they can immediately use. Locke justifies this shift by attributing money's value to mutual consent, writing, "Gold and silver, being little useful to the life of man in proportion to food, raiment, and carriage, have their value only from the consent of men" (§50). While this transition facilitates economic development, it also introduces inequality, challenging Locke's earlier emphasis on fairness and sufficiency.

The introduction of money marks a pivotal moment in Locke's theory of property, underscoring the tension between natural law and economic systems. By enabling unlimited accumulation, money undermines the natural limits that Locke initially imposed, leading to disparities in wealth and power. This shift raises critical questions about the role of consent through a social contract in economic systems, particularly in contexts where structural inequalities limit individuals' ability to participate freely. Locke's recognition of these challenges reflects his nuanced understanding of property, even as it exposes the limitations of his framework in addressing modern economic realities.

The Glorious Revolution

Over the past two decades, the role and significance of Locke's political ideas in English history and his involvement in political events have been reinterpreted. Scholars have revisited The Second Treatise of Government, examining its connection to the revolutionary movements of the time and its influence on theories of government. The Glorious Revolution revolved around three fundamental issues: 1) who should rule England, 2)what the nature of kingship should be, notably how government should be reformed, and 3) what the relationship between the Church and the new monarchy should be.

Locke's response to the Revolution also reflected the political and religious principles he had developed before 1688-89, particularly in the Two Treatises of Government, drafted in the 1670s and early 1680s, and A Letter Concerning Toleration. The ideas found in Locke's private writings were not sudden innovations; earlier political

treatises had already anticipated many of the complexities surrounding succession and authority that he would later articulate more fully in the Second Treatise. However, Locke's discussion of the importance of property remains uniquely independent within his broader political philosophy.

Property as the Purpose of Government

Locke's discussion of property extends beyond the state of nature into the realm of governance. He argues, "The great and chief end of men's uniting into commonwealths, and putting themselves under government, is the preservation of their property" (§124). Locke's insistence on consent further strengthens this connection, as he asserts, "The supreme power cannot take from any man any part of his property with his own consent" (§138). This principle reflects Locke's broader fear of tyranny, advocating for constitutional safeguards against arbitrary power.

Locke's emphasis on property as the foundation of governance also underscores its role in promoting social stability and economic prosperity. By protecting property rights, governments create the conditions for individual flourishing and collective progress. However, the potential for governments to overreach or prioritize the property of the powerful over the common good creates tension within Locke's framework. Locke's theory of property extends beyond individual ownership to encompass broader questions of justice and resistance. He writes, "Whenever the legislators endeavor to take away and destroy the property of the people, or to reduce them to slavery under arbitrary power, they put themselves into a state of war with the people" (§222). Here, Locke positions property as a safeguard against tyranny, emphasizing its role in protecting individual autonomy and ensuring governmental accountability. This principle underpins Locke's justification for rebellion, asserting that violating property rights constitutes a fundamental breach of the social contract.

This perspective resonates deeply in political philosophy and history, influencing revolutionary movements such as the American and French revolutions. By linking property to political resistance, Locke elevates it from an economic concern to a cornerstone of democratic governance. However, this elevation also invites critical scrutiny from Enlightenment era philosophers to contemporary critics of capitalism. Locke's emphasis on property may risk privileging ownership over other essential rights, especially in societies where wealth and land are unequally distributed. This concern, echoed in later Enlightenment thought, underscores the tension between safeguarding property and addressing broader social and economic justice issues. These debates remain highly relevant today, as modern democracies struggle to balance robust property rights with the need to ensure equitable access to civil liberties and public goods.

JEAN-JACQUES ROUSSEAU

Jean-Jacques Rousseau's critique of private property is a central feature of his political theory. While often associated with his later work, Rousseau's reflections on property also appear throughout his earlier writings. Rousseau argued that private property is not a natural right but a social construct that emerges from force, inequality, and deception. For Rousseau, the emergence of private property marks a decline from natural freedom to a system of social domination, where moral and political corruption are entrenched. Ultimately, Rousseau proposes a communal society where property is subordinated to the common good.

The Emergence of Property

Rousseau traces the origins of private property to a critical moment in human history when individual ownership was first asserted. For him, this moment marks a profound break from the communal relationships that defined early human life. In the Second Discourse, Rousseau writes, "The first person who, having fenced off a plot of ground, took it into his head to say this is mine and found people simple enough to believe him, was the true founder of civil society" (p. 141), an idea founded on deception. The claim that one person could "own" land was a conceptual shift that required others to accept that claim. For Rousseau, this was the true origin of civil society, not the creation of legal or moral rights but the beginning of social inequality. In this sense, private property is inherently unjust because it is founded on a lie: the idea that one person can own the earth and its resources, which belong to all.

For Rousseau, the transition from a communal way of life to a system of private property marks the beginning of human inequality. In the state of nature, before the advent of private property, humans were free and equal, and resources were shared communally. Rousseau envisions early humans living without competition, each taking only what they need and coexisting peacefully. However, as soon as private property was introduced, a class of landowners and those dependent on them formed, laying the foundation for a society built on economic and social

disparities.

Rousseau begins by answering the question posed by the Academy of Dijon: "What is the origin of inequality among men, and is it authorized by natural law?" By tracing the origins of inequality to the moment when humans first began to claim private property and establish hierarchical social structures, Rousseau can demonstrate how institutions such as private property, laws, and the state are inherently unnatural and serve to preserve the privileges of the wealthy at the expense of the common good. Rousseau is deeply skeptical about the legitimacy of property rights. Rather than viewing property as a natural right, he regards it as a social construct perpetuating inequality. Rousseau believes private property is not rooted in natural law but in human violence and coercion. Rousseau makes a crucial distinction between what is "natural" and what is "socially constructed."

Rousseau further develops the idea that property is the root cause of social inequality. He writes, "The repeated utilization of various beings in relation to others, must naturally have engendered in man's mind perception of certain relations" (p. 143). In this passage, Rousseau explains how introducing private property alters human relationships. Before property, humans lived in relative harmony, bound by mutual dependence and everyday needs. The creation of private property, however, introduces division. Once land is claimed as "mine" and "yours," people no longer view each other as equals or allies but as rivals, competitors, or enemies. Property creates a sense of individualism and alienation, where people begin to see each other in terms of what they own or do not own. The creation of private property establishes a social order defined by exclusion and competition. The individual who owns the land has power over those who do not, and the introduction of property marks the beginning of the social conflict. Rivalries, jealousy, and suspicion replace the egalitarian bonds that exist in the state of nature. In Rousseau's view, private property introduces artificial divisions that destroy the once-established communal harmony.

Rousseau's historical account of property suggests that the institution of private property is the source of social inequality, and that this inequality man-made and not found in man's natural constitution, he will continue to assign the divisions imposed by property as artificial, rhetorically placing it less than natural divisions of men. While earlier societies may have been relatively egalitarian, the introduction of property created a division between those who have and those who do not. The "owners" become the ruling class, while the "have-nots" are relegated to subjugation. This division fosters competition, jealousy, and greed, which Rousseau sees as morally corrupting. In Rousseau's view, the shift from communal living to a system based on private property is not merely an economic change but a moral decline.

Rousseau and the French Revolution

The influence of Jean-Jacques Rousseau on the French Revolution is a well-established topic in political theory, although few have gone beyond vague conclusions to provide a concrete analysis. Rousseau's work focused on ideals of virtue, love, and simplicity, rather than specific political structures. As such, it is more accurate to trace the direct influence of the revolution on his followers, such as Sylvain Maréchal, Babeuf, Charlotte Corday, and the poet Robespierre, disciples of Rousseau's ideas (Gordon H. McNeil, 1945).

The start of the French Revolution in 1789 marked a shift in the political impact of Rousseau's philosophy. While his writings did not directly shape political strategies, his advocacy for the general will and the use of the social contract created an emotional loyalty that resonated with revolutionary factions. Rousseau became a symbol, with different factions quoting him to support their causes. During the revolution's early years, the National Assembly and the revolutionary press frequently referenced Rousseau's ideas. His image became common at revolutionary ceremonies and political clubs (Gordon H. McNeil, 1945).

However, Rousseau's influence in the revolution was not simply political; it took on a more symbolic role. He was often depicted as more akin to a saint than a direct revolutionary leader. So, was Rousseau truly influential in the French Revolution? The most accurate answer is that his writings were needed, and a favorable environment was found to apply them. Rousseau's literary and political influence grew with the revolution, yet it could never fully escape the revolutionary context in which it was read.

The Corrupting Effect of Property

Rousseau argues that private property has profound

implications for human freedom. In the state of nature, humans are free, equal, and independent; however, introducing private property marks the loss of this natural freedom. He claims that the rivalry and competition spawned by property lead to inequality, escalating into perpetual conflicts between men and therefore governments, culminating in national wars (p. 161). As soon as property is introduced, individuals are no longer free. The pursuit of property creates dependencies, divisions, and social hierarchies. Property becomes the primary means by which individuals measure their worth and secure their societal status. As a result, human desires shift from meeting basic needs to acquiring and protecting wealth, thereby undermining the freedom of the state of nature.

Rousseau writes, "As long as [humans] applied themselves only to tasks that a single person could do and to arts that did not require the cooperation of several hands, they lived free, healthy, good, and happy" (p. 151). This statement encapsulates Rousseau's view of humanity in its pre-social state, living in small communities where individuals were responsible only for their needs. Their tasks were simple and did not require collective labor, which meant that people were self-reliant and free from the constraints that would later emerge with more complex social structures. According to Rousseau, this lifestyle allowed humans to maintain their natural freedom and autonomy, as they were not bound by the social obligations or dependencies that come with larger, more intricate cooperation systems.

Rousseau emphasizes that in this primitive state, individuals were not subject to the corrupting influences of social inequality or competition for wealth and resources. This simple way of life, Rousseau suggests, also contributed to physical health and moral goodness. There were no complex systems of social stratification or institutionalized power to corrupt human nature. Humans could live in a state of natural innocence, healthy in body and mind, unburdened by the anxieties and inequalities that would later define civilization. In this view, Rousseau contrasts the moral purity of early humans with the decline he believes occurred once societies began to evolve. Social divisions emerged as humans developed property rights, engaged in more specialized labor, and depended on one another for increasingly complex tasks.

The moral fall that Rousseau describes is a matter of material inequality and a more profound psychological shift. The desire to own and control leads people to abandon their natural sense of empathy and communal responsibility as he writes in the Second Discourse, "In fact, why did they give themselves superiors if not to defend themselves against oppression, and to protect their goods, their freedoms, and their lives, which are, so to speak, the constituent elements of their being" (p. 163). Property ownership enables specific individuals or groups to accumulate wealth and power, while the rest of society becomes increasingly dependent on those with property. In this system, equality is undermined, and social mobility becomes difficult.

Rousseau believed that property leads to the establish ment of laws that protect and perpetuate inequality. The first inequality, property, gives rise to a second, more pervasive, legal inequality. Once property becomes a social institution, laws are created to protect it. These laws, in turn, protect the interests of the wealthy, reinforcing the power structures that allow them to maintain control over the property and the wealth it generates. However, the laws that protect private property are not neutral or just; they are tools of oppression designed to keep the rich in power and marginalize the poor. This distortion of justice through law leads to the state's corruption, which Rousseau argues is no longer acting in the interest of the common good but in the interest of those who hold power through property. Property thus consolidates power, creating a cycle where the rich become richer, and the poor remain poor. Rousseau believes this inequality system corrupts society's moral fabric, leading to greed, envy, and social strife.

The Relationship Between Property and Political Power

Rousseau's central critique of modernity, namely that the growth of inequality, driven by property and the state, leads to the transformation of legitimate political authority into arbitrary power, a form of despotism that serves the interests of the few rather than the common good. Establishing private property and creating laws to protect it marked the beginning of social inequality. In other words, property ownership was legitimized through law, and society gradually accepted property as a natural right. However, as he further observes, this very progres-

sion led to a transformation of political power.

According to Rousseau, the initial political power, although stemming from laws designed to protect property, was legitimate; it was intended to ensure peace and order, thereby safeguarding the rights of all citizens. However, as property becomes concentrated in the hands of the few, the nature of political power changes. The "last stage" of this process is a corruption of political authority, wherein the legitimate power of the state, initially created to defend the common good, transforms into arbitrary power, used to maintain and protect the privileges of the wealthy few. This progression of inequality mirrors the trajectory of the political system itself. Establishing laws to protect property first legitimizes political authority. Still, over time, as the wealthy consolidate more power and resources, those laws come to serve the interests of the few rather than ensuring equality or fairness for all. Rousseau's assertion that the "last stage" of this process is the shift from legitimate power to arbitrary power emphasizes the corrupting influence of property on politics. Once property becomes entrenched and protected by laws, political authority ceases to be a vehicle for promoting the common good, becoming instead a tool for safeguarding the status quo.

When laws are in place to protect property rights, they institutionalize inequality, ensuring that the wealthy maintain their dominance. Rousseau's last stage, the transformation of legitimate power into arbitrary power, illustrates the profound moral and political corruption that he believes accompanies the growth of inequality.

Rousseau's argument that property leads to the rise of arbitrary power is not just a critique of economic inequality but a critique of how property influences the very structure of political power. The state's role in legitimizing private property marks the beginning of political corruption, as the legal system becomes increasingly skewed in favor of the property-owning class. Rousseau writes, "The meaning of these terms is better expressed by the terms poor and rich, since before laws a man did not have any other means of subjecting his equals" (p. 162). Thus, the political system becomes a mechanism for enforcing the arbitrary and unjust authority of the wealthy. This is why Rousseau argues that the state, far from being a neutral force for justice, becomes an instrument of domination. The more property is concentrated in the hands of a few, the more the law and political authority become tools of oppression, reinforcing social divisions and perpetuating inequality.

Rousseau's Call for Political Transformation

In Rousseau's Discourse on the Origin and Basis of Inequality Among Men, his call for political transition is deeply tied to his critique of private property and its role in corrupting society. He believes a radical transformation of political authority and property relations is necessary to return to a state of natural liberty and moral equality.

Rousseau's political philosophy is revolutionary. His idea of political transition is rooted in rejecting the property-based political system. For Rousseau, property is the key source of inequality. As wealth becomes concentrated in the hands of a few, the state's role becomes less about promoting the common good and more about maintaining social order and protecting private interests. In this system, the state is no longer a neutral force but a tool of the wealthy.

Given the deep connection between property and inequality, Rousseau argues that only a radical political transition can address the systemic injustice inherent in property relations. Rousseau does not propose minor reforms or adjustments to the existing system; instead, he calls for a complete overhaul of political and social structures. This transition would involve the abolition or radical reorganization of private property so that wealth is not concentrated in the hands of a few individuals.

In Rousseau's view, property must be redefined to prevent its concentration in a few hands and ensure that resources are shared more equitably. He is often interpreted as advocating for a form of collectivism or communal ownership, where property is no longer a private, exclusive right but a shared resource that serves the common good. This would allow the state to return to its primary function, serving the collective will and ensuring the equality and freedom of all citizens.

Rousseau proposes that to establish true freedom and equality, a new form of political organization must be created, one that is based on the general will rather than the protection of private property. The general will represent the collective interests of the people, and it is the foundation for the social contract that Rousseau envisions. In this contract, individuals would collectively agree to form a new kind of political order, one in which

the interests of the collective are placed above the interests of the few.

However, for the general will to function correctly, it must be free from the influence of private property. If property is concentrated in the hands of the wealthy, then the general will be distorted by the interests of the property-owning class. To correct this distortion, Rousseau suggests a revolutionary shift that removes the power of property and its influence on the state. This shift would ensure that the state is genuinely democratic, serving the interests of all citizens equally rather than protecting the privileges of a few.

Rousseau's call for political transition is intricately tied to his critique of private property. By abolishing the concentration of property and redistributing wealth, Rousseau envisions a society where laws and political institutions serve the common good, ensuring all citizens' freedom, equality, and justice.In this new order, power is no longer a tool of the wealthy but a mechanism for collective decision-making and the promotion of public welfare. Rousseau's vision challenges the foundational assumptions of modern political systems, proposing a radical rethinking of how property, power, and justice should be organized in society.

Rousseau in Contemporary Society

Rousseau's vision of a just society centers on the idea that private property must be subordinated to the common good. In his view, inequality and moral corruption arise when property becomes concentrated in a few hands, and laws protect privilege rather than promote collective well-being. Similarly, the Zapatista communities in Chiapas, Mexico, offer a contemporary example of resistance to privatization and neoliberal governance. These indigenous-led autonomous zones emphasize communal land ownership, direct democracy, and social equality, principles deeply resonant with Rousseau's critique of inequality (Miller, 2021). However, the Zapatistas operate through decentralized governance rooted in local traditions, and currently fail to hold an autonomous position in national governance.. Nevertheless, the Zapatista emphasis on solidarity, participatory politics, and collective ownership embodies Rousseau's core concerns with justice and the subordination of property to the common good.

Even modern welfare states in the Nordic region, such as Sweden or Norway, reflect certain aspects of Rousseau's thought. Their emphasis on redistribution, universal healthcare, and access to education aligns with Rousseau's insistence that laws and institutions serve the common good rather than entrenched privilege. However, property rights remain intact, and capitalism continues to define economic relations. Thus, while these societies temper inequality, they stop short of realizing Rousseau's call for collective ownership and a reconfiguration of political sovereignty, only partially fulfilling Rousseauan ideals

While no modern society fully embodies Rousseau's model of a communal political order, several reflect elements of his thought in practice. From the Zapatista communities to the egalitarian aspirations of eco-villages and Nordic welfare systems, Rousseau's influence endures in diverse and evolving forms. These examples demonstrate the enduring relevance and the practical challenges of implementing Rousseau's vision of subordinating property to the collective will to pursue a more just and equitable society. Patrick Riley's interpretation of Rousseau's concept of the general will is instrumental in understanding how Rousseau's critique of property ties into his broader political theory. His work offers a framework for critiquing how property-based inequalities perpetuate social divisions. Capitalist economies often prioritize individual property over the collective good, resulting in policies that protect private property at the expense of social welfare programs. By examining modern instances of wealth concentration, such as the growing power of multinational corporations and the increasing privatization of public goods, Riley's interpretation of Rousseau sheds light on the ongoing relevance of the general will in debates over economic policy and social justice.

Carole Pateman's feminist critique of property provides a gendered lens through which to analyze Rousseau's critique of modern society. In her influential work The Sexual Contract, Pateman argues that the concept of private property perpetuates economic inequality and is a tool for gender oppression (Okin, 1990). For Pateman, the traditional social contract, rooted in theories of property and individual ownership, has always been gendered, serving to exclude women from full participation in both political and economic life.

Pateman's critique builds on Rousseau's insight that property introduces artificial social divisions. Her work helps explain why the concentration of property and wealth in the hands of a few continues to affect women and marginalized groups disproportionately. Despite legal advancements toward gender equality, the concentration of property and resources remains a significant barrier to true gender equality, with women and marginalized

groups often excluded from the benefits of economic prosperity. To illustrate the relevance of Rousseau's critique in modern society, we can look at several contemporary case studies:

1. The Rise of Neoliberalism: Rousseau's critique is evident here, as these policies concentrate wealth in the hands of a few, undermining the common good and promoting social division.

2. Wealth Inequality and the 1%: In countries like the United States, the concentration of wealth among the top 1% of the population underscores the enduring influence of private property in perpetuating stark economic inequality. Rousseau's argument that political authority becomes a tool for maintaining inequality is reflected in the increasing political influence of wealthy elites, who use their resources to shape policy in their favor.

3. The Global South and Land Grabs: In many developing nations, the concentration of land and property in the hands of multinational corporations and wealthy elites has led to dispossession and environmental degradation. These "land grabs" have sparked protests from indigenous and local communities, who argue that the commodification of land violates the principles of the common good Rousseau championed.

Rousseau's critique of property and its corrupting influence on society remains deeply relevant today. By integrating the ideas of scholars such as Riley and Pateman, we can better understand how property continues to shape modern forms of economic and social stratification. The concentration of wealth, gendered inequalities in property ownership, and the persistence of class divisions reflect the enduring influence of Rousseau's insights on property and justice. Property remains a central issue in contemporary society debates over inequality, governance, and social justice. Rousseau's argument that property leads to the corruption of politics and culture provides a critical framework for analyzing how modern forms of inequality are entrenched and perpetuated. Whether through the lens of neoliberalism, feminist critiques, or socialist thought, Rousseau's critique of property is a powerful reminder of the moral and political consequences of wealth concentration in modern societies.

PROPERTY AND INEQUALITY: A COMPARATIVE ANALYSIS

Property is critical in political philosophy, shaping foundational debates on justice, inequality, and the state's role. Rousseau and Locke, two eminent Enlightenment thinkers, offer distinct yet profoundly influential theories of property. Rousseau critiques property as the root of inequality and social decay. Conversely, Locke defends property as a natural right essential to liberty and economic development. By examining their theories, we uncover a fundamental philosophical divergence: Rousseau views property as a corrupting force that entrenches inequality, while Locke considers it a cornerstone of human flourishing.

Locke's Defense of Property as a Natural Right

In the Second Treatise, Locke constructs his theory of property within a broader framework of natural rights, which he posits existed in the state of nature before the formation of organized governments. Property plays a particularly critical role because it embodies the application of individual labor to the natural world. He declares, "Whatsoever, then, he removes out of the state that nature hath provided and left it in, he hath mixed his labour with, and joined to it something that is his own, and thereby makes it his property" (Locke, §27). This labor theory of property is central to Locke's argument: human effort transforms nature into personal possessions, making ownership justifiable and morally defensible.

Locke's theory emphasizes the creative and productive nature of labor. By mixing one's labor with the earth's resources, individuals assert control over those resources and fulfill their duty to use what is freely available. Individuals have a moral obligation to utilize resources responsibly. His view reflects a broader belief that the natural world is given to humanity for sustenance and improvement, with labor acting as the mechanism through which value is added.

However, Locke limits property acquisition to prevent misuse and ensure fairness. The "sufficiency condition," as articulated in Section 27, requires that individuals leave "enough, and as good," for others, which prevents hoarding and overexploitation. This theoretically ensures everyone can access the resources necessary for survival and flourishing. Despite this ethical framework, Locke acknowledges that the introduction of money disrupts the natural balance of property distribution. In the state of nature, individuals could only appropriate as much as they could use without waste. Money, however, facilitates wealth accumulation beyond immediate needs, and the consent of individuals to the use of funds effectively nullifies the sufficiency condition, allowing inequality to emerge. He writes, "Men have agreed to a disproportionate and unequal possession of the earth" (Locke, §50),

signaling his recognition that economic systems based on money lead to significant disparities in wealth.

Nevertheless, Locke defends this shift, arguing that the economic progress enabled by private property and the use of money outweighs the drawbacks of inequality. He sees property accumulation as a driver of productivity and innovation, ultimately benefiting society. Locke contends that land and resources held in private ownership are more likely to be improved and cultivated, contributing to the common good. Locke's theory of property underscores a dynamic tension between his natural law principles and the practical realities of economic development. While he initially grounds property rights in individual labor and a moral obligation to leave enough for others, he ultimately reconciles the inequalities produced by introducing money and large-scale property ownership by emphasizing their contributions to societal progress.

Rousseau's Critique of Property and Its Role in Inequality

In stark contrast to Locke, Rousseau sees the emergence of property as the pivotal moment in humanity's descent from natural freedom into inequality and social corruption. He declares, "The first person who, having fenced off a plot of ground, took it into his head to say this is mine and found people simple enough to believe him, was the true founder of civil society" (Rousseau, p. 141). For Rousseau, this moment represents the origin of artificial inequality, a fundamental shift transforming human relations and sowing the seeds of greed, competition, and conflict. Unlike Locke, who celebrates property as an expression of labor and liberty, Rousseau views it as the root of social and moral decay.

Rousseau emphasizes that early humans were content and egalitarian, their needs balanced by the abundance of nature and the absence of societal constructs like wealth and status. The establishment of property disrupted this natural equilibrium. Rousseau argues that inequality begins when someone stakes a claim on land or resources. He writes: "The fruits belong to all and the earth to no one" (Rousseau, pp. 141-42). For Rousseau, property was not merely a tool for survival or progress but an exclusion device, dividing humanity and fostering envy and resentment. Rousseau highlights how the institutionalization of property created a cascade of inequality. Once individuals began to amass wealth and resources, they sought to protect their possessions, forming laws and governments. Rousseau views these institutions as inherently corrupt, serving the interests of the wealthy and powerful rather than ensuring justice or equality. He writes, "the most frightful disorder followed the destruction of equality; thus the usurpations of the rich" (Rousseau, p. 157).

In Rousseau's view, the wealthy manipulated the creation of laws to legitimize their dominance, disguising oppression as order and fairness. Far from protecting the common good, governments became instruments for perpetuating inequality and securing the elite's privileges. Rousseau does not envision a return to a state of nature or a purely communal existence; instead, he critiques laissez-faire capitalism. He argues that the problems of inequality are not intrinsic to nature but are socially constructed. Rousseau notes that "as long as they applied themselves only to tasks that a single person could do… they lived free, healthy, good, and happy" (Rousseau, p. 151). However, when individuals begin to rely on one another, equality dissipates, and property emerges, necessitating labor and thus introducing inequality.

This development alienated individuals from their natural freedom and equality. Rousseau contrasts the independence of humans in the state of nature with the dependence and subjugation that result from property and society. Under the new social order, people became trapped in cycles of competition and comparison, seeking status and recognition rather than genuine well-being. Rousseau laments that property and its attendant institutions "destroyed natural freedom for all time, established forever the law of property and inequality, and for the profit of a few ambitious men henceforth subjected the whole human race to work, servitude, and misery" (Rousseau, p. 160).

In essence, Rousseau sees property not as a source of human flourishing but as the origin of societal decay. It institutionalized divisions between the rich and the poor, the powerful and the powerless. It introduced a host of vices, including greed, ambition, and exploitation, that were absent in the state of nature. For Rousseau, the civil society founded on property rights is a perversion of humanity's original state, replacing natural freedom and equality with artificial hierarchies and alienation, setting him apart from Locke.

KEY DIFFERENCES

The most striking divergence between Locke and Rousseau lies in their assessments of property's origins, moral implications, and societal consequences. While Locke champions property as a natural right derived from labor and a cornerstone of personal liberty and societal advancement, Rousseau condemns it as an artificial

construct that breeds inequality, corruption, and dependence. While Locke advocates for the pre-existence of property rights grounded in natural law, Rousseau critiques property as a socially constructed right that lacks inherent legitimacy.

At first glance, the societal structures proposed by Locke and Rousseau appear pretty similar; both advocate for governance that reflects the people's will. However, their underlying philosophies reveal profound differences. Locke's social contract primarily exists to protect pre-existing rights, which are seen as natural and immutable. Since the source of these rights lies outside the state's authority, the government is inherently limited in its powers, with no higher authority to which individuals can appeal. In stark contrast, Rousseau's notion of the general will impose no such limitations. For Rousseau, rights are constructed by the community, allowing society the flexibility to transform itself radically in pursuit of civil equality. Consequently, while Locke's framework tends to preserve existing inequalities, Rousseau's approach mitigates them.

Property as Natural vs. Artificial

For Locke, property is a natural right grounded in the labor individuals invest in the natural world. He argues that laboring transforms resources from a state of everyday use into personal possessions, a process that aligns with natural law and the divine will. He writes, "God gave the world to men in common; but since he gave it to them for their benefit … it cannot be supposed he meant it should always remain common and uncultivated" (Locke, §34). For Locke, property rights emerge naturally from human effort, and the cultivation of land benefits not only the individual but society as a whole.

Locke believes that individuals have an indisputable claim to their bodies, and, by exercising this claim, individuals can extend ownership to external resources. He argues that labor bestows legitimacy on property ownership: it is through the act of labor that one can justly claim resources as one's own. Therefore, property is a natural right underpinned by a collective agreement, allowing the state to form later. Rousseau rejects this perspective, asserting that property is a product of human convention and invention following the formation of society. Locke sees the state as securing pre-existing rights, whereas Rousseau views it as the creator of rights.

Rousseau dismisses any notion of returning to a natural form of possession or primitive communal sharing (Rousseau, p. 116). He emphasizes property's social and transformative nature, advocating for a society where each citizen possesses at least a minimal share of private property. He acknowledges that inequality is inherent in human societies but argues against extreme disparities. Rousseau articulates two forms of inequality: natural or physical inequality, and suggests that a balance between these inequalities is essential; otherwise, it contradicts the natural order.

Rousseau contends that there is nothing natural about the institution of private property. For him, property is a right that cannot exist before a social contract; it is not a product of reason or natural law but rather the result of the most "clever usurpation" orchestrated by a few "ambitious men" for their profit (Rousseau, p. 160). Rousseau perceives property as a name given to a usurpation that gained state sanction, transforming into an irrevocable right, but he denies it any intrinsic legitimacy. Rousseau distinguishes between mere possession and moral rights. In the state of nature, individuals can physically control their holdings, but this form of ownership is precarious. While one can empirically claim control over property, such grounds lack justification beyond brute force. Strength fundamentally sustains property rights, highlighting the moral ambiguities surrounding ownership.

The Role of Property in Inequality

Locke acknowledges that inequality can arise from property ownership, particularly with the advent of money, which enables wealth accumulation beyond immediate needs. However, he views such inequality as inevitable and beneficial if it arises from voluntary agreements and does not violate the sufficiency condition. He defends economic disparities by arguing that private property incentivizes productivity and innovation, which benefits society. Even those with less wealth in a property-based society ultimately enjoy greater comfort and security than they would in a state of nature without private property.

Rousseau, by contrast, identifies property as the primary source of inequality and the root cause of social decay. He argues that establishing property allowed the wealthy to consolidate power and exploit the poor and writes, "It is manifestly against the law of nature, in whatever manner it is defined … a handful of men be glutted with superfluities while the starving multitude lacks necessities" (Rousseau, p. 181). Rousseau critiques how property transforms social relations, creating hierarchies based on wealth and fostering dependence among the lower classes. He further condemns governments as complicit in this process, asserting that they serve to protect the interests of the propertied elite. As he puts it, "Subjects

no longer have any law except the will of the master, not the master any other rule except his passions, the notions of good and the principles of justice vanish (Rousseau, p. 177).

Both Rousseau and Locke utilize the state of nature to formulate criteria for governmental legitimacy, positing that a government is legitimate if it fosters conditions preferable to those in the state of nature. However, their definitions of these preferred conditions differ. For Locke, authority arises from citizen consent. In contrast, Rousseau emphasizes social equality and the moral obligation to act in a manner that contributes to the general will and enhances the welfare of all individuals within that society

Rousseau adopts a critical tone towards property acquisition, highlighting the corrupting influence of greed on society. He illustrates how the rise of private property leads to inequality and a persistent inner conflict for individuals. Instead of allowing people to live as complete beings, society entraps them in a mode of existence that alienates them from their natural feelings. Rousseau argues that civilized individuals struggle to realize their true potential because external values dictate their lives. One critical aspect of Rousseau's critique is his belief that ostentatious wealth poses a more significant threat to liberty than the mere possession of property. The quantity and nature of property, rather than the act of ownership itself, are essential concerns for Rousseau, primarily because of the material dependency such wealth imposes on others. A primitive man, despite his apparent limitations, lives in harmony with his environment, enjoying self-sufficiency and a lack of external conflict. In contrast, modern man is trapped in a web of social expectations, leading to dissatisfaction and torment. Rousseau acknowledges that this decline has been a gradual and complex process, influenced by various physical conditions that have shaped the development of human capacities

While Locke emphasizes protecting pre-existing rights, Rousseau advocates for a radical reimagining of property and equality within society. His critique of modern civilization highlights the detrimental effects of private property on human nature and social relationships, suggesting that true fulfillment lies in a return to the communal values that foster authentic human connections. Rousseau argues that in society, individuals become enslaved by their subservience to the thoughts and wills of others. Initially, primitive humans possessed inherent capacities such as perfectibility and freedom. Still, these traits remained dormant as they became self-aware beings with needs and desires often in conflict with those of others. Relationships in this early social structure were primarily familial, allowing natural freedom without significant constraints.

However, establishing property marked a pivotal shift that made political society possible, perhaps even inevitable. With the distinction between "mine" and "thine," identity became tied to possessions rather than inherent qualities. The desire for material satisfaction replaced a contentment derived from simply being. As individuals began to strive for the accumulation of riches, they became valued for their intrinsic worth and the emotional satisfaction tied to their ownership. Consequently, the rich and powerful manipulated the poor and weak into a position of permanent subjugation.

Rousseau posits that society's foundation should be a social contract grounded in shared interests and the general will, prioritizing equality. According to him, the sovereign should govern based on this general will, where the community's needs precede personal preferences. Thus, the community can determine how property rights should be allocated. Society creates equality by ensuring everyone possesses something, while no one has excessive wealth.

At first glance, the societal structures proposed by Locke and Rousseau appear pretty similar; both advocate for governance that reflects the people's will. However, their underlying philosophies reveal profound differences. Locke's social contract primarily protects pre-existing rights, whereas, for Rousseau, rights are constructed by the community, allowing society to transform itself radically in pursuit of civil equality.

Government and the Protection of Property

Locke views property protection as one of the central purposes of the government. He writes, "The great and chief end, therefore, of men uniting into commonwealths, and putting themselves under government, is the preservation of their property" (Locke, §124). Locke's social contract envisions a system where individuals consent to form a government that safeguards their natural rights, including property, from threats such as theft or invasion.

Locke states, "The reason why men enter society is the preservation of their property," suggesting that this goal motivates individuals to unite and form societies (Locke, §222). For Locke, legitimate property existed before the establishment of the state. Consequently, individuals join society not to create new rights but to protect existing ones. As property rights originate in natural law, innate and inalienable, the state's power to confiscate must be

limited. Locke emphasizes property protection when delineating the boundaries of sovereign authority, underscoring that it would be absurd for individuals to submit to societal restrictions without receiving security over their holdings. Rousseau argued that governments are designed not to protect the rights of all but to preserve the privileges of the wealthy. He sees the social contract not as a voluntary agreement among equals but as a tool of manipulation by the elite. Rousseau contends that laws and political institutions legitimize inequality by presenting it as a natural and just order, masking the exploitation at its core.

While both thinkers explore property in their state of nature, they come to disparate conclusions about private property's role in a just government and its value to man's nature. While Rousseau acknowledges Locke's assertion that "nobody hath a right to take their substance or any part of it from them, without their consent; without this, they have no property at all," he fundamentally disagrees with Locke's positive interpretation of property's emergence (Locke, §138). Locke posits that property rights are inherent and predate government establishment, stemming from natural law. In contrast, Rousseau argues that property rights arise only through a social contract, essential for their legitimacy. This distinction reflects their divergent visions of political authority: Rousseau's concept of the general will emphasizes civil equality, while Locke's social contract seeks to preserve inequality for the common good.

Locke and Rousseau present opposed views on property and its role in human society. Their conflicting perspectives highlight fundamental tensions between liberty and equality, individualism and collectivism, and progress and morality, tensions that remain central to contemporary debates on property and justice.

POINTS OF CONVERGENCE AND THEIR LIMITS

Despite their stark differences, Locke and Rousseau share some common ground in their reflections on property and its implications for society, particularly in their acknowledgment of property's transformative impact on human relations and the organization of society. However, these points of convergence are limited by their divergent conclusions about whether property is ultimately beneficial or detrimental to human flourishing.

Both Rousseau and Locke employ the concept of the state of nature to explore the foundations of political legitimacy and the role of private property. Their differing approaches highlight the complexities of human nature, society, and governance. Rousseau's critique of property reflects a desire for a more equitable society, while Locke's emphasis on rights and consent underpins his vision of legitimate government. These philosophical inquiries underscore the ongoing relevance of their ideas in contemporary discussions about property, equality, and justice.

The Transformative Power of Property

Both Locke and Rousseau recognize that the introduction of property marks a significant turning point in human history, profoundly reshaping societal structures and individual relationships. They agree that property is not merely about material possession but about power, control, and the reorganization of human interactions.

Locke acknowledges the transformative potential of property, observing that its acquisition and protection are fundamental to the development of organized society. Rousseau similarly identifies property as a transformative force, but his analysis highlights its disruptive consequences. He notes that the claim to exclusive ownership was when humanity departed from its natural state of equality and freedom. Like Locke, Rousseau understands property as fundamental to civil society. However, where Locke sees it as a unifying and stabilizing force, Rousseau views it as a source of division and corruption.

Despite Rousseau's acknowledgment of property's role in fostering a just society, his overall tone regarding the emergence of private ownership is critical. He recognizes that social values, shaped by property, alienate individuals from their original nature, replacing it with an artificial identity. People begin to exist not by their true selves but rather by adapting to how they believe others perceive them. Rousseau is acutely aware of the dangers inherent in accumulating goods as society evolves. He emphasizes the psychological implications of this change, particularly the inevitability of overconsumption and greed that arise from property.

Rousseau argues that overconsumption and greed are intrinsic to the human condition once property becomes a defining aspect of social life. Rousseau's analysis underscores the transformative effects of property on human nature and social values. He calls for reevaluating how social values and individual identities are constructed in the context of materialism.

The Role of Labor in the Use of Resources

Both Rousseau and Locke agree that human interaction

with the natural world involves labor, though they differ on how labor justifies property rights. Locke asserts that labor transforms nature into property, stating:

By his labor, he does, as it were, enclose it from the common. Nor will it invalidate his right to say, everybody else has an equal title to it. Therefore, he cannot appropriate and enclose without the consent of all his fellow-commoners, all mankind (Locke, §32). He ties property rights to the productive use of resources, arguing that labor improves land and resources, making them valuable and morally claimable. Rousseau does not deny the importance of labor but emphasizes its communal, necessity-driven nature in the state of nature. He writes that in early human life, "Societies, multiplying or spreading rapidly, soon covered the entire surface of the earth, and it was no longer possible to find a single corner in the universe where one could free oneself from the yoke" (Rousseau, p. 160). Theoretically, Rousseau would respond to Locke's assertion by disputing Locke's claim that labor is mutually exclusive from the common, a discrepancy that Rousseau does not highlight. For Rousseau, labor in the state of nature was not about ownership but survival, with individuals taking only what they needed from the land.

While Rousseau and Locke recognize labor as integral to human interaction with nature, Locke elevates it as the basis for ownership. At the same time, Rousseau sees it as a pragmatic activity devoid of the concept of property. For Rousseau, property embodies a fundamental contradiction in human life. While he acknowledges it as a necessary tool for civil society's legitimacy and justification, he sees it as a corrupting influence that fosters natural inequalities among men. In his view, if humanity could perpetuate a state of nature, that state would be preferable. However, the transition to civil society becomes unavoidable with the development of consciousness and language.

Rousseau views private property as a crucial bargaining tool in human interactions and governance, essential for maintaining the rule of law. He suggests property is necessary for establishing a just and civil society, particularly within a democratic framework. Rousseau articulates specific conditions under which property rights may be valid. He allows for proprietary rights within a just social contract framework, emphasizing that the state's rights supersede those of its subjects. Rousseau believes private property can thrive, provided it is regulated and restricted to prevent divisions and vice. The principal threat to liberty arises from conscious awareness rather than from the existence of private property, since this awareness can destabilize social, economic, and political tensions.

Limits of Convergence

Their fundamental disagreements about property's moral and societal implications undermine the apparent overlap in Locke's and Rousseau's views. For Locke, property is a positive force rooted in natural law and labor that fosters human progress and social stability. He writes, "God gave the world to men in common; but… He gave it to the use of the industrious and rational" (Locke, §34), suggesting that property rights reward productivity and reason, aligning with divine intention.

However, Rousseau rejects the moral justification of property, seeing it as a construct that entrenches inequality and subjugates the majority to the will of the few. Even in their acknowledgment of the role of property in shaping civil society, the limits of their convergence are evident. For Locke, government and laws are created to protect property rights and ensure justice, fulfilling the promise of progress. Rousseau, in contrast, sees government as complicit in perpetuating inequality, writing "the origin of society and laws, which gave new fetters to the weak and new forces to the rich" (Rousseau, p. 160). Rousseau argues that property was not inherent in human nature; it required significant societal progress and intellectual development to be fully understood and embraced. He posits that private property arises from human opinion rather than material necessity, as individuals seek wealth primarily to distinguish themselves from others rather than for practical benefits.

Rousseau asserts that while a government cannot legitamately confiscate the goods of its citizens, it can regulate the acquisition of property to prevent excessive accumulation. He acknowledges the initial acquisition of property as unavoidable but views this accumulation as a source of inequality. Despite his critical stance on property, Rousseau does not advocate for its complete abolition; instead, he recognizes that no just government can eliminate property or restrict its accumulation altogether. In contrast, Locke focuses on protecting property against encroachments and advocates for a type of ownership that best upholds the laws of a just society, highlighting the dangers of excessive wealth and its potential to undermine liberty.

Contemporary Debates and Applications

Locke and Rousseau's political theories have profoundly impacted political thought, particularly regarding prop-

erty, governance, and the concept of the common good. While Locke's labor theory of property has often been lauded as a foundational idea in liberal political philosophy, Rousseau's critique of property has shaped egalitarian and revolutionary ideologies. However, both thinkers' ideas, though revolutionary in their time, continue to spark debates about the nature of justice, equality, and individual rights in contemporary society

One of the most controversial aspects of Locke's theory of property is his sufficiency condition, an idea fundamental to liberal theories of private property used to justify historical injustices, particularly in the context of colonial land appropriation. Scholars such as Bruce Ackerman have argued that Locke's theories were invoked to explain the dispossession of indigenous peoples in the Americas, as European colonizers appropriated land under the assumption that it was unowned or in need of development (Lawrence, 2005).

Locke justified land appropriation on the grounds of improving the land through labor. However, this view overlooks the cultural, political, and social ties that indigenous peoples had to their land, rendering their dispossession not just an economic act but a moral violation of their natural rights. Contemporary debates about land reparations and indigenous peoples' rights to reclaim their land echo these critiques of Locke's theory. Modern theorists, such as Waldron, have challenged the application of Locke's theories to colonial contexts, arguing that Locke's framework for property requires revision to account for these historical injustices. In contrast, Rousseau's concept of the general will challenge the liberal democratic conception of politics. Some see Rousseau's vision of governance, in which individuals subordinate personal interests to the general will, as an idealistic approach to democracy. However, its practical application in modern, pluralistic societies remains a contention.

Scholars like Patrick Riley have highlighted the feasibility of Rousseau's general will in contemporary society, suggesting that it assumes too much consensus and is prone to manipulation by those in power (Riley, 1986). The general will may function in small, homogeneous societies in its ideal form. Still, it becomes increasingly difficult to apply in modern democratic systems, where diversity and pluralism make it harder to define a collective will. Rousseau's vision of collective sovereignty, emphasizing direct participation in the political process, faces significant challenges in the modern era of representative democracy. Furthermore, criticisms of Rousseau include his seemingly utopian and nostalgic image of state nature, a prehistorical myth that fails to encapsulate the full violence and naivete of humans in a pre-society existence.

Nonetheless, Rousseau's idea of the general will inspires democratic thinkers and movements, particularly those seeking to address global inequality and political alienation. Jürgen Habermas's theory of deliberative democracy, for example, shares Rousseau's commitment to collective decision-making through public discourse, offering a more pragmatic avenue for realizing the general will in modern governance (Habermas, 1975).

Locke's labor theory of property has had a lasting influence on the development of liberal property rights, particularly in the context of intellectual property. In today's digital economy, Locke's labor theory has been invoked to justify intellectual property laws that grant creators exclusive rights to their ideas, inventions, and works of art. However, this application of Locke's theory raises new questions about the nature of ownership in an era where intellectual labor is often disconnected from tangible property.

In a world where automation and artificial intelligence are replacing traditional forms of labor, Locke's labor theory faces increasing challenges. If labor is no longer the primary source of value creation in society, then Locke's emphasis on the connection between labor and property becomes problematic. Andrew Feenberg and David Harvey have argued that the rise of automation presents a new challenge to traditional theories of property, as labor becomes less relevant in determining ownership and value. This critique suggests that Locke's theory may be ill-equipped to address the complexities of modern economies. Rousseau's critique of property has important implications for the climate justice movement, which argues that exploiting natural resources for private gain has led to environmental degradation and global inequality. Rousseau's belief that private property disrupts society's natural harmony can be applied to critiques of the capitalist economic system, which often prioritizes profit over environmental sustainability.

The philosophical debates between John Locke and Jean-Jacques Rousseau regarding property and governance continue to shape contemporary political discourse. Locke's labor theory of property, while foundational to liberal economic thought, faces significant challenges in modern debates over colonialism, intellectual property, and automation. Meanwhile, Rousseau's critique of property offers valuable insights into the moral consequences

of economic inequality and the need for collective action in the face of pressing global challenges such as climate justice.

CONCLUSION: LOCKE, ROUSSEAU, AND THE ENDURING COMPLEXITY OF THEIR IDEAS

The writings of John Locke and Jean-Jacques Rousseau represent two of the most significant contributions to Enlightenment political philosophy, particularly in their analyses of property, governance, and human nature. Despite their differences, these thinkers profoundly shaped revolutionary ideals and continue to influence contemporary debates on freedom, equality, and the role of government. This paper has argued that while Locke and Rousseau converge in acknowledging the transformative power of property and its centrality to the development of civil society, they diverge sharply in their assessments of its moral and societal implications. By juxtaposing Locke's labor-based justification for property with Rousseau's critique of property as a source of inequality, this essay has demonstrated the depth of their philosophical differences and their enduring relevance.

The central argument of this paper is that Locke and Rousseau present fundamentally opposed visions of property's role in society, with Locke viewing it as a natural right that underpins liberty and progress. At the same time, Rousseau condemns it as a corrupting institution that entrenches inequality and alienates individuals from their natural freedom. These contrasting perspectives reflect more profound philosophical differences in their views of human nature, the state of nature, and the purpose of political institutions. Locke's emphasis on individual rights, limited government, and the productive benefits of private property resonates with liberal democratic principles. In contrast, Rousseau's focus on collective welfare, critique of social hierarchies, and moral costs of inequality challenge the assumptions of property-based societies, advocating for more egalitarian structures.

The analysis also highlights points of agreement between Locke and Rousseau, particularly their recognition of property as a transformative force in human history. Both thinkers recognize that property has reshaped societal structures and human relations, pivotal in transitioning from a state of nature to an organized society. However, their agreement ends there. While Locke celebrates this transition as a means to secure freedom and prosperity, Rousseau mourns it as a loss of equality and natural harmony.

Locke's ideas raise challenging questions about the inequalities that arise from property ownership, particularly in the context of colonialism and capitalism, which often operate in tension with his sufficiency condition, the requirement to leave enough for others. On the other hand, Rousseau offers a scathing critique of property as a root cause of social inequality and moral decay. His vision of an egalitarian society governed by the general will counters Locke's individualism. However, Rousseau's romanticization of the state of nature and his radical critique of property also invite skepticism. How can modern societies, relying on complex economic systems, reconcile Rousseau's vision of equality with the practical realities of resource distribution and governance?

Further exploration of Locke and Rousseau's ideas could deepen our understanding of their relevance to contemporary issues. For instance, debates over wealth inequality, environmental sustainability, and the privatization of common goods reflect Rousseau's concerns about the corrosive effects of property on society. Similarly, Locke's labor theory of property might be revisited in light of emerging issues such as intellectual property rights and data ownership. His emphasis on labor as the foundation of ownership raises questions about how value is created and distributed in digital and automated economies. Another promising avenue for exploration lies at the intersection between Locke's and Rousseau's ideas. While their perspectives often appear opposed, their shared concern for property's ethical and societal implications suggests a potential for synthesis. For example, Locke's recognition of the need to limit resource appropriation aligns, at least in principle, with Rousseau's emphasis on ensuring fairness and collective welfare. Examining these alignment points may offer new insights into balancing individual rights and social justice.

Despite their differences, both thinkers grapple with the complexities of property as a transformative force in human history, offering contrasting but equally profound critiques of its role in shaping civil society. Their philosophies influenced the American and French Revolutions and continue to inform contemporary discussions on governance, justice, and human rights. Ultimately, Locke and Rousseau's ideas underscore the richness and diversity of Enlightenment thought, offering a framework for exploring enduring questions about freedom, equality, and the ethical foundations of political and economic

systems. Their legacy invites us to reflect on the ongoing challenges of creating societies that honor individual rights and collective welfare. This tension remains as relevant today as it was during the Enlightenment.

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Automated Hepatic Vein Segmentation and Attenuation Measurement in Contrast-Enhanced CT Scans: A Reliable Algorithmic Approach

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ABSTRACT

Accurate segmentation and attenuation measurement of hepatic veins (HV) in contrast-enhanced computed tomography (CT) scans may improve diagnostic and image-guided therapeutic interventions in the liver. Automation could improve the identification of HV and streamline workflows that involve localization of the blood vessels in the liver. This study adapts a previously developed vessel segmentation algorithm, designed for the portal vein, to automatically identify and measure attenuation in hepatic veins. The algorithm was applied to a publicly available dataset of 82 CT scans, and the identified regions were manually validated. The left, middle, and right HV were identified, and attenuation was recorded in Hounsfield units (HU). Mean pixel attenuation values were calculated for the algorithmic and manually segmented regions for each CT scan. These two sets of values were compared by calculating the root mean square error (RMSE), which was evaluated against a 95% confidence interval to assess agreement. Analysis of the data demonstrated strong concordance between the algorithmic and manual attenuation measurements, indicating the method's reliability for HV segmentation. These findings support the broader application of automated segmentation algorithms for liver vasculature analysis.

INTRODUCTION

Computed tomography (CT) is a critical diagnostic tool in modern medicine and is used for the detection and characterization of a variety of diseases. In CT scans, contrast and image quality plays a major role in the identification of anatomical structures. Diagnostic abdominal CT often employs contrast enhancement using intravenously administered iodinated contrast agents. The detection of lesions enhanced by contrast agent is a difficult diagnostic task which depends on good image quality and advanced image processing technologies (Jensen et al., 2019). Despite use of image-enhancing methods, consistency poses a challenge due to the sensitive nature of CT imaging (Flouris et al., 2022). The full extent of the consequences of poor CT imaging on clinical outcomes is not yet fully understood and diagnostic quality remains an important concern.

There is a lack of post-computational quality enhancement and insufficient data to support the development of new methodologies (Bae, 2010). To establish a baseline for diagnostic quality, automated processing can analyze CT images and extract image quality metrics, especially related to contrast enhancement (Szczykutowicz et al., 2021). Automated identification systems in CT imaging have the potential to reduce variability, save time, and offer economic advantages (Wu et al., 2024; Kapoor et al., 2020).

This study adapts a previously designed segmentation algorithm trained to identify portal veins (McCoy et al., 2024). ML and deep learning were employed to refine the algorithm, enabling it to accurately measure attenuation values across a broad range without requiring labor-intensive manual contouring. The algorithm has been built upon and augmented to better locate HV, which are narrower and located superior to the portal vein in the liver. This initial iteration serves as a foundation for further advancements in automated segmentation, particularly for liver vasculature, and hopes to enhance diagnostic precision in contrast-enhanced CT imaging.

Accurate identification of hepatic veins is clinically important because these vessels serve as major

anatomical landmarks in liver imaging and surgery. Variations or obstructions in the hepatic veins are associated with conditions such as hepatic vein thrombosis, cirrhosis, and Budd–Chiari syndrome. In oncology, precise vein visualization is essential for differentiating tumors from vascular structures and for preoperative planning in liver resection or transplantation. Improved segmentation of hepatic veins can therefore enhance surgical navigation, reduce procedural risk, and support early diagnosis of vascular complications.

PROGRAM AND DATASET

ImageJ is a widely used open-source platform for image processing and analysis in biomedical research (Schindelin et al., 2012). Its accessibility and extensive library of plugins make it an ideal tool for implementing and testing algorithms, including those for segmentation. Fiji, an enhanced version of ImageJ, additionally offers compatibility with advanced machine learning making it the software of choice for running the derived algorithm.

The National Institutes of Health Clinical Center provided 82 contrast-enhanced 3D abdominal CT scans captured approximately 70 seconds after intravenous contrast injection during the portal venous phase (Roth et al., 2016). The dataset includes 53 male and 27 female subjects, comprising 17 healthy kidney donors scanned prior to nephrectomy. The remaining 65 patients were selected by a radiologist based on the absence of significant abdominal pathologies or pancreatic cancer lesions. The subject ages range from 18 to 76 years, with a mean age of 46.8 ± 16.7 years. The CT scans have a resolution of 512x512 pixels, with varying pixel sizes and slice thicknesses between 1.5 and 2.5 mm. The scans were acquired using Philips and Siemens MDCT scanners operating at a tube voltage of 120 kVp. The dataset is publicly available for download (version 2, updated 2020/09/10). Note that cases 25 and 70 were duplicates of scan 2 and were therefore excluded from the dataset.

METHODS

When importing a CT scan from the dataset into ImageJ, each case was imported as an image sequence. The algorithm was then run on the opened window. The presets for image brightness and contrast were set to a minimum value of -274 and maximum value of 238, while the unsigned 16-bit range was set to automatic. Window center was set to -18 and the set width to 512, ensuring uniformity. The algorithm also had the CT images reoriented during preprocessing to align with the standard radiological orientation, where the axial view displays the posterior side (spine) at the bottom of the image, and the liver appears on the viewer's left (anatomical right) side. This adjustment ensured consistency with conventional abdominal imaging layouts, facilitating accurate interpretation and analysis.

Through ML, the algorithm was trained to seek out "tube-ness" and other hallmarks of HV anatomy. The algorithm used the Tubeness filter in ImageJ, which enhances tubular structures by analyzing voxel intensity and local curvature (Sato, 1998). A sigma value of 2 was chosen to match the size of hepatic veins, and the top 20% of the brightest voxels were selected as vessel candidates. These were refined using a secondary mask limited to 50–500 HU to exclude non-vascular tissue. After a brief morphological cleanup, connected components were labeled as individual ROIs representing hepatic vein segments. Once finished, a list of regions of interest (ROI) was generated, and a new separate window that displays the area of the identified segments was opened (see Figure 1). To verify the accuracy of these segments, the segmented window was overlaid on the original CT scan, creating a composite image that enabled easier manual review, as shown in Figure 2. Each ROI was labeled numerically and cross-checked for accuracy. Correctly identified ROIs were documented and further categorized into left, middle, and right HV locations for ease of analysis.



Figure 1. The resulting ROIs from the algorithm displayed spatially before merger.

For consistency, only segments that were disconnected from the inferior vena cava were accepted. In addition, segments were only accepted up to a bifurcation point, meaning post-bifurcation segments of the HV were not accepted and excluded from analysis. However, segments that include the bifurcation point but went beyond the point itself were still considered valid. ROI that included

the HV but erroneously identified other structures were excluded to maintain the integrity of the dataset.

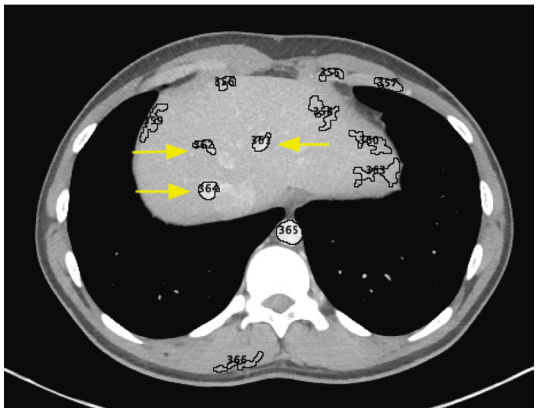
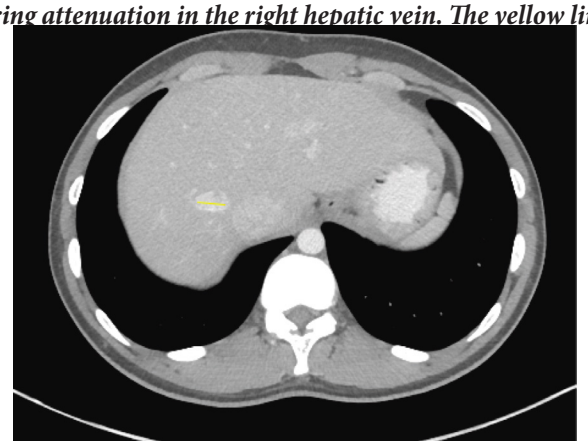


Figure 2. The merger of the CT scan and ROIs. Correctly identified left, middle, and right hepatic veins are shown by the arrows.

This approach was implemented to ensure consistency and accuracy in the segmentation and attenuation measurements (McCoy et al., 2024). By excluding segments disconnected from the inferior vena cava, only anatomically relevant portions of the HV were analyzed, maintaining focus on the primary vein structures. Limiting the segmentation to regions up to a bifurcation point ensured that the analysis reflected the main venous pathways, avoiding the complexity and variability introduced by smaller, post-bifurcation branches. Accepting segments that include the bifurcation point but not those extending beyond it allowed for standardized measurements while still capturing critical anatomical features of the HV. This methodology reduces variability and ensures reliable comparisons between algorithmic and manual segmentations. If, despite these efforts, a CT scan produced no viable segments, no ROIs were recorded.

Mean pixel values of the HV were also recorded. First, the left, middle, and right HV were identified manually, without the use of the algorithm. In ImageJ, the "Pencil" tool was used to measure the attenuation in Hounsfield units (HU). A standard procedure was developed for manual measurements, where the slice chosen for the measurement was the one that best displayed the HV structure. Then, a line was placed from the left-most point of the HV to the right-most point, ensuring the line remained entirely within the HV (see Figure 3). The line was then measured to obtain the mean pixel value. This procedure was followed for each type of HV. If the HV could not be visually identified, the entry was recorded as "null." The attenuation value for the ROI was determined by identifying the ROI closest in slice position to the HV and repeating this process for all vein locations. Similarly, "null" was recorded in cases where the HU could not be measured.

Figure 3. An example of the standard procedure for measuring attenuation in the right hepatic vein. The yellow line



was drawn from the left-to-right, within the vein at its most prominent position.

STATISTICAL ANALYSIS

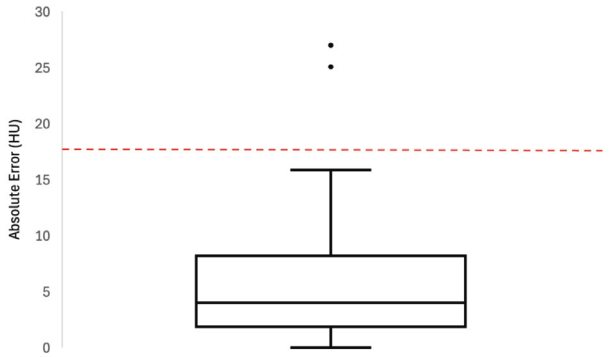
To assess the data, it was important to aggregate the results so that a single data point could be used to compare the manual and algorithm-derived measurement. The averages of the left, middle, and right HV attenuation values for both the manual and computational regions were calculated. The two averages were then subtracted to determine the error. The root mean square error (RMSE) was subsequently calculated. Based on clinical experience and known variability in CT attenuation measurements, an RMSE of less than 20 was considered acceptable, reflecting the normal range of variation expected between repeated scans or manual measurements. This threshold indicated that the algorithm was successful in identifying HV attenuation. To further evaluate the algorithm's reliability, the 95% confidence interval (CI) of the RMSE was calculated.

RESULTS

Of the 80 CT scans, the algorithm identified HV in 50. The error ranged from 0.279 to 27.0 and the RMSE was calculated with n=50, yielding a value of 9.05 HU. This result is less than 20 HU, indicating clinical significance and strong performance by the algorithm. There were 54 cases where the algorithm failed to identify a left, middle, or right HV that human annotation did. However, there were no cases where the algorithm identified an HV that human annotation could not. The 95% confidence interval for the RMSE ranged from 7.21 to 10.9, within

which the RMSE value falls, supporting the validity and reliability of the result.

Figure 4. Distribution of hepatic vein attenuation error



(HU) across all CT scans with both manual and algorithmic measurements available (n = 50). The dashed line marks the 20 HU threshold for clinically acceptable variation, below which the disagreement between manual and algorithmic measurements is considered within normal diagnostic tolerance.

DISCUSSION

The results of this study demonstrate the effectiveness of adapting a vessel segmentation algorithm to identify and measure attenuation of HV in contrast-enhanced abdomen CT scans. The significantly low RMSE indicates clinical success of the algorithm, showing it can successfully identify HV attenuation. The CI also supports this claim, as the RMSE falls within the acceptable range. These findings highlight the potential for leveraging machine learning and automated segmentation tools to streamline the identification of HV, reduce manual effort, and enhance workflows that utilize the location and intensity of HV. However, the variability in error and the inability of the algorithm to identify HV in 30 scans suggest areas for improvement, particularly in challenging anatomical or imaging conditions.

CT scans using iodinated contrast media have contrast phases that describe certain stages of contrast enhancement to anatomy. After a pressure injected (IV) contrast agent is introduced to the blood stream, patients go through the following phases: early arterial, late arterial, portal venous, nephrogenic, and excretory. For HV identification, portal venous phase CT scans are widely accepted to be preferred (Rosselli, 2024). The CT scans in the dataset were all collected in the portal venous phase, however there was significant variation in visibility between scans. This variation could be attributed to several factors, including differences in patient anatomy, timing of the scan relative to the contrast injection, contrast agent dosage, and scanner calibration or settings. In CT scans where there was higher contrast in the liver, the algorithm identified the HV more often than in scans with lower contrast, likely due to the enhanced definition of vascular structures provided by better contrast distribution. Such variability highlights the importance of optimizing imaging protocols to ensure consistent diagnostic quality.

At this stage, human annotation was required to differentiate correct ROIs from erroneous ones identified by the algorithm. Development is ongoing to program the system to perform this task automatically, which will reduce the reliance on manual intervention and improve efficiency. With further iterations of the algorithm, the time required for HV identification could be drastically reduced, allowing for faster and more consistent segmentation. Eventually, ML and DL models are expected to refine the process further by displaying only correct ROIs, minimizing errors. The application of this software would not only save time for doctors but also streamline bulk analysis of data, improving scalability for research and clinical workflows. As the system matures, it has the potential to significantly reduce manual workload while enhancing the accuracy and reliability of HV identification, benefiting both clinical diagnostics and large-scale studies.

CONCLUSIONS

The adaptation of the portal vein segmentation algorithm to identify and measure hepatic vein attenuation in contrast-enhanced CT scans proved successful. The algorithm demonstrated strong agreement with manual measurements, as indicated by a low RMSE and consistent confidence intervals, underscoring its reliability. These results highlight the potential for automated segmentation tools to enhance diagnostic workflows and streamline analysis in clinical scenarios requiring the localization of the hepatic vein.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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Cultural Perceptions and Emerging Technologies: Investigating Biosensor Adoption Among South Asians with Type 2 Diabetes

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ABSTRACT

South Asians in the United States face disproportionately high rates of Type 2 diabetes, yet critical self-monitoring practices remain overlooked. This oversight leads to issues with complex medication regimens, motivation, and internal, familial, and social stigma within families dealing with Type 2 diabetes. This study questions how cultural perceptions and interpersonal attitudes shape urban American South Asians' views on Type 2 diabetes management, specifically, in which ways these perceptions and attitudes affect continuous glucose monitoring habits within the community, especially with wearable technology and biosensors—analytical devices that detect biological signals such as glucose and convert them into measurable outputs—as an alternative to glucometers. Biosensors, defined as analytical devices that detect biological signals such as glucose levels and translate them into measurable electronic outputs, represent a subset of wearable technologies designed for continuous, non-invasive monitoring. This study used a mixed-methods approach combining surveys and ethnographic needs assessments with 17 participants from the Greater Houston Area. Findings reveal that perceptions of diabetes as a chronic and definitive condition, heightened social awareness of showcasing a visible illness, and both personal and familial stigma significantly influence the acceptance and usage of wearable biosensors. Moreover, this study contributes valuable insights into how cultural stigma, concerns about device visibility, and perceptions of cost and usability shape South Asians' preferences for biosensor models. Participants expressed greater acceptance of less intrusive designs, such as wristbands, glasses, and skin patches, compared to implants or mouthguards. Although limited by a small sample size and geographic focus, this study identifies the need for options that are consistent with these cultural norms to develop a holistic, inclusive approach to living with Type 2 diabetes that supports more equitable and culturally responsive approaches to Type 2 diabetes management.

INTRODUCTION

Diabetes mellitus is approaching epidemic proportions worldwide. Currently, 589 million adults aged 20–79 are living with diabetes, a number projected to rise to 853 million by 2050 (IDF Diabetes Atlas, 2025). Diabetes mellitus is a chronic medical condition characterized by elevated blood sugar levels, occurring when the pancreas fails to produce sufficient insulin or when the body's cells become resistant to insulin. Type 2 diabetes mellitus (T2DM) is now a major global health challenge.

South Asians, including individuals with ancestry from the Indian subcontinent, experience disproportionately high rates of T2DM. They represent one of the highest percentages of Type 2 diabetes cases worldwide. In the United States, South Asians are up to four times more likely to develop T2DM compared to non-Hispanic whites (Kanaya et al., 2014). Despite this elevated risk, significant disparities persist in health literacy, diabetes self-management practices, and glycemic control within this population. Within the American South Asian community, there remains a gap in awareness and adoption of newer glucose monitoring technologies. Traditional methods, such as glucose meters, are supplemented by emerging options like electrochemical biosensors, wearable devices, tracking applications, and biofluid glucose sensors. However, cultural stigma, low health literacy, and limited access to culturally attuned resources hinder the effective adoption of these technologies. For example, many diabetes

education materials and technology instructions are not available in South Asian languages or do not incorporate culturally specific dietary guidance, limiting their relevance and usability. Self-monitoring practices often suffer due to complex medication regimens, motivational barriers, and stigma within families (Sohal et al., 2015), leading to poor glycemic control and increased diabetes-related complications.

For South Asian immigrants in particular, these challenges are exacerbated by dietary shifts, health misconceptions, and a lack of preventive care models that align with cultural values. There has been limited research investigating how cultural perceptions shape the adoption of continuous glucose monitoring tools among South Asians in the U.S. In light of the persistent challenges faced by South Asians in managing Type 2 diabetes, emerging technologies such as biosensors offer a promising opportunity to transform blood glucose monitoring through noninvasive, continuous, and user-friendly tracking that can be adapted to diverse cultural contexts, ultimately improving health outcomes. This study seeks to address that gap by exploring how interpersonal attitudes, stigma, and cultural norms influence the acceptance of biosensors as alternatives to traditional glucometers.

CULTURAL PERCEPTIONS

A review of the current literature shows that personal cultural beliefs were found to be a vital component in actively shaping decision-making when it comes to changing diet and lifestyle or choosing monitoring and treatment methods. For example, the study by Misra & Khurana (2009) explored how the prevalence of obesity and the metabolic syndrome is increasing within the South Asian population due to Type 2 Diabetes Mellitus (T2DM) and cardiovascular disease (CVD). More specifically, the study explored how rapid urbanization, changing lifestyles, phenotypic features, correlations between determinants, subclinical inflammation, psychological stress, genetic and perinatal factors, migration, and socioeconomic factors contributes prevention and control of the metabolic syndrome in South Asians. The results from this showed a high prevalence of metabolic syndrome and associated cardiovascular risk factors in economically disadvantaged people located in urban slums and rural areas due to nutrition, lifestyle, and socioeconomic transitions, which in turn increases affluence, urbanization, mechanization, and migration. A combination of psychological stressors associated with urban settings, genetic predisposition, and environmental pressures contribute to increased metabolic strain. These factors, along with patterns of 'catch-up' obesity and other physical traits predominant in South Asians, collectively elevate cardiometabolic risk. The findings showed that increasing awareness of Type 2 Diabetes and the associated risk factors can help with prevention strategies in the South Asia community to due to the high cardiometabolic risk associated with the Sout Asian demographic.

Furthermore, Imran et al. (2015) explored how South Asian's perceptions and cultural views influence self-management of diabete s Type 2 in America. More specifically, this study focused on perceptions, cultural factors, and practical constraints. The study found that the main barriers to healthy behaviors was regular physical exercise, consuming low-glycemic foods, attending physician's appointments, difficulty in adapting to dietary changes, and poor understanding of disease severity and complications. The presence of cultural factors complicating self-care and adherence to traditional social roles also influence South Asian's management of diabetes and it associated complications. The most concerning responses in this qualitative study were the lack of knowledge and perceptions associated with diabetes, coupled with difficulties due cultural practices and religious obligations.

Similarly, Sohal et al's 2015 study systemically review studies that explore South Asian diabetic patient's perspective on barrier and facilitators to glucose management. Specifically, the study explored why diabetes management was so poor in South Asians, despite being a leading demographic in the diagnosis of type-2 diabetes mellitus, by investigated attitudes on interactions with health care workers, diet, exercise and medication adherence, core components of diabetes management. The studies identified language and communication discordance as a significant barrier to diabetes management. This often reflects a lack of accommodations for non-English-speaking patients, such as English-only clinics, untranslated medical instructions, or limited availability of interpreters. Additionally, patients reported inconsistent wellness behaviors related to following physician guid-

ance in self-management, limited adaptations to curate a South Asian–appropriate diabetic diet, social responsibilities, stigma, and persistent misconceptions. Moreover, an overarching theme was a lack of culturally informed understanding and knowledge surrounding diabetes medication management, which itself was not adapted to meet the needs of South Asians.

PRESENT SOLUTIONS AND INTERVENTIONS

For T2DM, current solutions include glucometers, lifestyle changes, such as improved diet and increased physical activity, together with pharmacological interventions, including metformin, insulin, and other medications. Bhurji et al. (2016) explored and compared management intervention systems of Type 2 diabetes for patients of South Asian origin from Pakistan, Bangladesh, or India in both the Western and Eastern realms. Specifically, the study examined how the large gap in diabetes control within the South Asian population is influenced by lifestyle and knowledge through a comparative analysis of randomized controlled trials (RCT), a systemic review of prospective pre-post-test observational studies, and differences in data collection of blood pressure, lipid levels, and anthropometric measures from the studies.

Bhurji et al. (2016) found that there was a disparity in the number of articles in each hemisphere: seven were conducted in the UK and sixteen were conducted in India. The intervention studies included seven mixed, eight educational-based, and three exercise based, which reflected themes of culturally specific educational practices and resources in the ones from the UK, while the Indian ones focused on yoga, resistance exercise, and dietary education.These findings expressed that diabetes management interventions for South Asian patients were varied because of the limited success in HbA1c reduction, which differed by region and intervention. Studies in India reported measurable HbA1c improvement, with yoga- and exercise-based interventions reducing HbA1c by 0.5–1.8% across trials. In contrast, larger European studies demonstrated minimal change, generally 0–0.4% and often not statistically significant. These numbers highlight the regional differences in intervention effectiveness and reinforce the need for both surface and deep cultural adaptations in diabetes management programs. The results highlighted meta-analyses of RCTs showing that culturally adapted diabetes management significantly improves HbA1c, extending consideration to both surface adaptations (superficial characteristics such as people, language, places, and food) and deep adaptations (integration of sociocultural concepts, historical context, and psychological factors unique to a population). This distinction directly aligns with the needs identified in my own study, where South Asian participants expressed preferences for biosensor options that matched cultural norms, addressed stigma, and reduced device visibility, indicating that both surface and deep adaptations are necessary for effective adoption.

Chittem et al. (2022) expanded the challenges with current methods by exploring the inhibiting factors to self-monitoring of blood glucose (SMBG) and managing medication by comparing Type 2 diabetic Indian patients, their primary family member (PFMs) and physicians accounts. Specifically, the study examined their varying experiences through recorded interviews and determined that three main issues were identified: confusion in the complex medication regimen, alternative therapies recommended by family due to social stigma, and financial stress of the illness. The findings from the study expressed that training physicians' emotional connectedness and communication, empowering patients to communicate concerns, and educating patients on managing Type 2 diabetes will reduce the negative implications. It expresses the shared ideals of the Indian immigrants in the United States with Type 2 diabetes, offering an explanation towards their behavior and response in SMBG, as the social stigma, the cultural attitudes, and the lifestyle choices. Similarly, Gary & Hirsch (2013) explored the real-world utilization and costs of self-monitoring blood glucose (SMBG) for individuals with insulin-treated diabetes. More specifically, it was designed to explore the discrepancies in the world frequency and true expenditures related to SMBG and its implications on diabetes type 2 treatment and management. The researchers provided commentary on each study objectives, strengths, and weaknesses, analyzing the relevance and key points of each study and how it can used in discussion related to SMBG. The source is credible, as it has been cited and referenced in multiple studies SMBG with self-care and management practices for diabetes Type 2. With the current practices in use for SMBG in Type 2 Diabetes, the biomedical field and newer tools such as the Dexcom G6 continuous glucose

monitor are gradually reshaping glucose monitoring by providing ongoing sensor-based readings instead of periodic finger sticks. However, existing evaluations have primarily focused on utilization and cost metrics, without addressing physiological accuracy or user experience, which limits their relevance for tailoring more advanced, patient-centric solutions. This underscores a clear need for next-generation tools—namely, biosensors—that can provide continuous, non-invasive, and context-aware glucose monitoring while aligning with the cultural and behavioral realities of diverse patient populations.

BIOSENSORS

In the context of Type 2 diabetes management, particularly among populations facing cultural and logistical barriers to consistent self-monitoring, biosensors offer a compelling alternative to traditional glucose monitoring tools. These analytical devices function by coupling a biological recognition element, such as an enzyme or antibody, with a physicochemical detector that translates interactions with specific analytes, such as glucose, into measurable signals. Unlike conventional glucometers, which rely on intermittent finger-prick readings, biosensors can enable continuous, non-invasive glucose tracking. This provides real-time physiological data that better reflect patient behavior, adherence patterns, and metabolic variability. Such functionality is especially important in heterogeneous cultural environments and culturally specific populations where sporadic monitoring or stigma can hinder effective disease management. Bolla & Priefer (2020) explored the ways in which non-invasive devices and future prospects perform in blood glucose monitoring. Specifically, the study looked into how blood glucose monitoring and it's the role in medication dosage adjustment can aid in management of burdens and adherence while checking glucose levels. The study compared the non-invasive blood glucose monitoring technology and devices such as urine, breathalyzer, finger detection, Metabolic heat conformation (MHC), Near-infrared spectroscopy (NIR), Mid-infrared spectroscopy (MIRS), earlobe, ultrasound, electromagnetic sensors, Thermal emission spectroscopy (TES), hand, tears, optical polarimetry system, and retina pigmentation. The findings from the study showed that there are significant efforts put towards researching non-invasive technology, but the adherence for blood glucose monitoring can be accredited to the current methods that are considering painful, expensive, and a hassle. The market can be modified to accommodate the approaches to be more accessible, less expensive, and accurate to improve the quality of life for the diabetic patients.

Similarly, Bruen et al. (2017) explored recent advances in glucose monitoring for diabetics using noninvasive methods that rely on biological fluids other than blood. More specifically, the study examined interstitial fluid, sweat, breath, saliva, and ocular fluid within the context of developing a personalized, daily-use biosensor. The authors critically reviewed each option, assessing their versions, growth within the field, prospects, and comparative effectiveness. Their findings showed that while wearable biosensors play an important role in continuous noninvasive diabetes monitoring, further clinical evaluation is still needed for these technologies to achieve broad adoption, despite strong commercial interest. Current consumer devices, such as fitness bands and smartwatches, offer only surface-level feedback about daily activity and provide limited insight into clinical health practices that could meaningfully improve day-to-day diabetes management. This limitation becomes even more consequential in communities where cultural norms, language barriers, or limited health literacy already make following medical guidance more difficult. Without tools that translate everyday behavior into culturally appropriate clinical actions, these devices fail to address the deeper behavioral obstacles that influence biosensor adoption among many South Asian patients.

Furthermore, Johnsten et al. (2021) explored what factors need to be improved in biosensing technologies for users. More specifically, the study looked into the precision, repeatability, wearability, and accessibility to end-users among other challenges that affect the perspectives on the development of biosensors for glucose monitoring. The findings from the study reflected the attention that the developments in nanotechnology, biomedical engineering, and biomaterials is attracting, comparing the various methods on their type of biofluid use, the mechanisms, recognition molecules, signal readout, sensitivity, and advantages. The study compiled together general challenges and perspectives for the biosensors, such as high costs limiting accessibility, developmental setbacks, biofouling, sensors lifetime, and calibration. The study outlined the optimal design for a continuous glucose monitoring

biosensors as having an overall long sensor life, being accurate, being accessible, and being affordable to the community in order to be beneficial for the diabetic community.

GAP

Diabetes is deeply shaped by culture and individual context, and the increasing prevalence of Type 2 Diabetes Mellitus (T2DM) within South Asian communities in the United States demands urgent attention. Despite efforts to improve health literacy and promote culturally adapted management strategies, there remains a critical gap in understanding how cultural beliefs, stigma, and daily practices influence self-monitoring behaviors. While biosensors are emerging as promising tools for continuous, non-invasive glucose monitoring, there is limited research on how these technologies are perceived, accepted, or utilized within South Asian populations. Specifically, there is a lack of data on how factors like family dynamics, visibility of disease, or cultural discomfort with technology shape biosensor adoption in this demographic. This study questions to what extent are current monitoring tools, and the assumptions behind their design, aligned with the lived experiences of South Asian individuals managing T2DM? Addressing this gap is essential to developing culturally responsive and clinically effective interventions.

THESIS

This study explores the complex interplay between cultural perceptions, healthcare interventions, and emerging biosensor technologies in efforts to enhance health literacy, self-management, and glycemic control among South Asians living with T2DM in the United States. By examining these components together, the goal is to identify barriers to effective diabetes management and propose culturally responsive, technologically informed strategies to improve long-term outcomes in this underserved population. To accomplish this, the study draws on a mixed-methods approach that combines a review of existing literature, thematic analysis of cultural and behavioral factors, and evaluation of current biosensor trends to understand both user-side challenges and technological limitations.

METHODOLOGY

This study employed a mixed-methods design integrating quantitative surveys with a qualitative ethnographic needs assessment. This approach enabled both statistical trends and cultural context to be examined, generating a more comprehensive understanding of how South Asians in the United States perceive biosensor technologies for Type 2 diabetes management. Mixed methods were selected because quantitative data can highlight patterns in self-monitoring behaviors, while ethnographic analysis provides the cultural framing necessary to interpret those patterns. To ensure consistency and clarity in the quantitative measures, all survey items were reviewed for coherence and alignment with the study's objectives prior to distribution.

Survey Design and Administration

The survey instrument (Appendix A) was adapted from validated questionnaires on diabetes self-management and technology use (e.g., Imran et al., 2015; Sohal et al., 2015). To ensure clarity and appropriateness, all survey items were reviewed for coherence and alignment with the study's aims before distribution. The final survey contained 25 items organized across four domains: (1) demographic and health background, (2) diabetes management practices, (3) perceptions of monitoring technologies, and (4) cultural stigma and attitudes. Completion time was approximately 10–12 minutes. Participants were recruited through voluntary response sampling at community sites with high South Asian participation, including temples, churches, and cultural centers in the Greater Houston Area. Eligibility criteria included being ≥18 years of age, identifying as South Asian, and reporting a diagnosis of T2DM. Although gender and age distribution were not used as recruitment criteria, demographic data were collected to contextualize the sample and interpret patterns in responses. Participation was anonymous and voluntary, with informed consent obtained electronically. Surveys were distributed via QR code and hyperlink.

Ethnographic Needs Assessment

To complement survey findings, an ethnographic needs assessment was conducted using secondary sources and contextual analysis rather than direct fieldwork. Prior qualitative studies of South Asian communities with T2DM (e.g., Imran et al., 2015; Sohal et al., 2015) and publicly available information on cultural practices in Houston religious and community institutions were analyzed. Primary ethnographic observation was not feasible

due to time constraints and limited access to community sites during the study period, so secondary materials were used to situate survey responses within the broader cultural landscape. This approach allowed examination of themes such as dietary practices, family involvement in health decisions, stigma surrounding visible medical devices, and cultural expectations regarding chronic illness, providing interpretive depth and ensuring that survey results were culturally grounded.

ANALYSIS

Quantitative survey responses were analyzed descriptively, generating frequencies, distributions, and cross-tabulations across demographic variables. Qualitative data from open-ended survey items and the ethnographic needs assessment were thematically coded using an inductive approach. Emergent themes, such as stigma, family dynamics, device visibility, and cost concerns, were compared across data sources to identify consistent cultural barriers. Triangulation of survey and ethnographic findings enhanced validity by showing that patterns identified in the survey, such as stigma, family involvement, and device visibility, also appeared in cultural context analyses, reinforcing that numerical trends aligned with lived experiences.

LOGICAL DEFENSE

Venkatesh et al. (2012) investigated how acculturation affects glycemic control in Asian Indian adults with Type 2 diabetes. Using the Suinn-Lew Asian Self-Identity Instrument alongside sociodemographic questions, anthropometric measures, and self-management questionnaires, the study linked acculturation with HbA1c outcomes. This structured, replicable design demonstrates the value of combining cultural measures with diabetes management indicators. The present study mirrors this approach by adapting surveys and qualitative components to examine how cultural identity and stigma shape biosensor adoption among South Asians in the Greater Houston area.

Similarly, Chittem et al. (2022) explored barriers to self-monitoring of blood glucose among Indian patients, their family members, and physicians. Using semi-structured interviews, they identified key issues including medication complexity, family-driven alternative therapies, and financial strain. This study underscores the importance of accounting for family dynamics and stigma in diabetes management. The current research extends this insight by assessing how these same cultural pressures influence attitudes toward biosensor technologies through a survey-based approach rather than interviews.

Through this mixed-methods design, the study evaluates both quantitative measures (e.g., frequency of glucose monitoring, HbA1c awareness, medication use) and qualitative themes (e.g., device visibility, stigma, family influence). Likert-scale questions were used to quantify preferences for specific biosensor designs, while open-ended responses were thematically coded to capture cultural and attitudinal nuances. This structure allows the study to generate both measurable trends and culturally grounded explanations of biosensor adoption.

LIMITATIONS

The study's methodology is constrained by its reliance on convenience sampling and a relatively small participant pool, 17 respondents, which may limit the generalizability of findings beyond South Asians in the Greater Houston area. While voluntary response surveys capture valuable insights from motivated participants, they may underrepresent individuals with limited engagement in community organizations or lower health literacy. These limitations are acknowledged to contextualize the results and highlight the need for larger, more diverse studies in the future.

ETHICS

The proposed methodology complied with ethical research practices and was reviewed under a Glenda Dawson High School IRB application for permission to collect data from human subjects and publicly present the findings. Participation was voluntary, and informed consent was obtained electronically through a required check-box agreement before survey access was granted. No personally identifying information was collected, and responses remained anonymous throughout the study. Data were stored securely, and all records will be destroyed within six months of project completion. These procedures safeguarded participant confidentiality while ensuring compliance with ethical standards for human subjects research. types more prone to error.

DISCUSSION

Faced with the common use of traditional glucometers, this study investigates how cultural perceptions and

interpersonal attitudes shape urban American South Asians' management of Type 2 diabetes. Specifically, it examines how these perceptions influence continuous glucose monitoring habits, particularly in relation to wearable biosensors as alternatives to glucometers.

Key Findings

Among the 17 participants surveyed, several themes emerged. First, diabetes was frequently described as a chronic and definitive condition, which contributed to feelings of resignation and reduced motivation for daily monitoring. Second, visibility of disease management was a consistent barrier: participants expressed discomfort with devices that drew attention to their condition, reporting stronger acceptance of discreet biosensors such as wristbands, patches, or glasses over implants or mouthguards. As one participant noted, "I just don't want people staring at something on my arm." Third, stigma—both personal and familial—was a recurring factor shaping attitudes toward biosensor use. Finally, concerns about cost and usability reinforced selective adoption, with participants preferring technologies that minimized financial and technical burdens. By highlighting these patterns, the study situates biosensor adoption within the broader cultural and social dynamics of South Asians in the Greater Houston Area, expanding on prior research that has largely focused on rural populations in South Asia.

Data Analysis

A total of 77 survey responses were collected, of which 17 met the inclusion criteria: identifying as South Asian (India, Pakistan, Bangladesh, Nepal, Bhutan, Sri Lanka, or Maldives), residing in the Greater Houston Area (Harris, Fort Bend, Montgomery, Brazoria, Chambers, Galveston, Liberty, and Waller Counties), and having a self-reported diagnosis of T2DM. The average participant age was 51.3 years, with the average duration of living with T2DM ranging from 6–10 years. The most commonly reported medications were metformin and Januvia, with an average use of 4 years. Participants reported an average A1C level of 4.8 and checked their blood glucose approximately once per day using a glucometer. Because this value falls below the typical clinical range for individuals with Type 2 diabetes, it likely reflects self-report error or misinterpretation of the question (e.g., reporting fasting glucose or ideal targets rather than laboratory A1C values). As a result, A1C data were interpreted cautiously and were not used as a clinical indicator in subsequent analysis. For self-management, 70.6% of participants reported following a diabetes-specific diet, with common strategies including "low carb," "keto," "restricting sugar and carbs," "less rice," and "chicken, egg, and vegetables." One recurring pattern was the reduction of rice intake, a culturally significant staple in South Asian diets. As one respondent explained, "I try to cut back on rice, even though it's hard at family meals." This tension reflects a broader pattern noted in the literature, where South Asian patients often struggle to balance culturally meaningful foods with medically recommended dietary changes, highlighting how cultural expectations shape adherence to self-management practices.

Additionally, 76.5% of participants reported using natural remedies and treatments, such as "cinnamon," "walking exercise," and "fenugreek water." The reliance on these approaches demonstrates the integration of traditional and home-based practices into diabetes care. While such remedies provide a sense of familiarity and cultural alignment, they may also reflect gaps in access to or trust in conventional biomedical management strategies.

In the Likert section, the stimulus questions revealed that each individual's definition of living with T2DM varies from individual to individual, as found in previous studies in the field based on Figure 1.

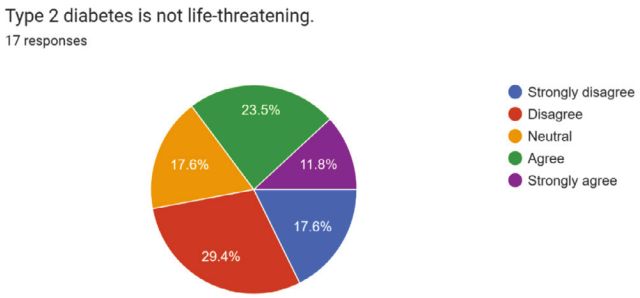


Figure 1. Distribution of participant responses (n = 17) to the statement "Type 2 diabetes is not life-threatening"among South Asians in the Greater Houston Area.

When exploring the relationship between the individual and T2DM, two perspectives were addressed: the obvious social, mental, and physical issues that come with T2DM serve as a factor that plays into their decision-making and journey with T2DM. 63% both agreed with the feel-

ing of anxiety, impaired confidence in everyday activities, and a heightened, stressed awareness of one's health and physical discomfort in monitoring, furthered by any side effects and interference with daily activities for long periods or physical activities with T2DM.

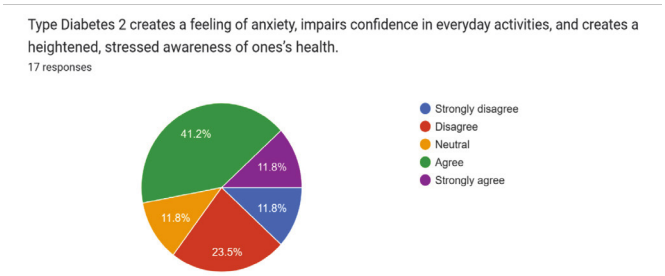


Figure 2. Distribution of participant responses (n = 17) to the statement "Type 2 diabetes creates feelings of anxiety, impairs confidence in everyday activities, and heightens stress and health awareness."

However, there seems to be a sense of dependence and trust in glucometers, showcasing that the South Asians of the Greater Houston Area are willing to use glucometers for regular monitoring.

The most prevalent personal beliefs that participants reported were "There is wrong information about curing diabetes," "It is in my family, lifelong, and therefore I have to live with it," and "I have to avoid junk food." There were also optimistic responses such as "I believe that it potentially helps in personal growth and resilience in the face of challenges, including those related to diabetes management." When the participants were asked about biosensors and any preliminary knowledge, 52.9% responded yes, sharing that they knew of its "role in continuous monitoring of blood sugar," "painless as it checks blood sugar without poking," and the Dexcom. However, because these responses were self-reported, they may be subject to recall bias, social desirability bias, or limited prior exposure to biosensors, which constrains the accuracy and generalizability of these findings.

In rating each of the five choices of biosensors presented to the participants in Figure 4, there was dislike expressed for options that seemed socially uncomfortable or would cause discomfort despitebeing non-invasive, such as the mouthguard. Yet, some more minimally invasive were shown as interest, such as the skin patch, with the most preferred biosensors being practical, such as the wristband and the glasses.

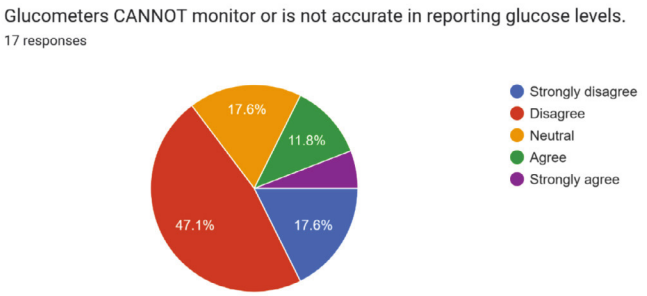


Figure 3. Distribution of participant responses (n = 17) to the statement "Glucometers cannot monitor or are not accurate in reporting glucose levels."

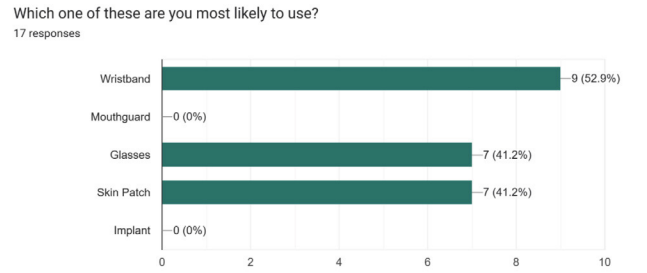


Figure 4. Preferred biosensor device types reported by participants (n = 17), including wristband, glasses, skin patch, mouthguard, and implant options.

When analyzing biosensors, the same participants shared similar sentiments; 63% agreed that this alludes to a sense of dependence and trust in biosensors, showcasing that the South Asians of the Greater Houston Area are willing to use biosensing for regular monitoring. The 41.2% who said that they are neutral on the costs, user-friendliness, and effectiveness biosensors showcase the discrepancies in their knowledge of biosensors despite knowing the baseline of what they do for monitoring for T2DM.

The same sentiment surrounding social discomfort appeared less significant with biosensors than with glucometers, as around 47% of participants disagreed with the statement that biosensors caused embarrassment. This suggests a greater sense of comfort and assurance with biosensors compared to traditional glucometers. Participants indicated that wearable devices such as wristbands or patches felt less intrusive and socially visible than finger-prick testing, which often draws unwanted atten-

tion in public or family settings. In this way, biosensors may reduce stigma by minimizing the visibility of disease management and decoupling daily monitoring from overt reminders of illness. This finding aligns with earlier observations about cultural perceptions of diabetes in South Asian communities, where visible signs of illness are often associated with shame, social judgment, or familial concern. By reducing these symbolic and social burdens, biosensors present an opportunity not only for improved monitoring but also for culturally responsive diabetes care.

NEW UNDERSTANDING

After analyzing the data, this study finds that cultural attitudes surrounding biosensors primarily stem from T2DM's chronic nature and its perceived sense of inevitability, particularly given the strong genetic component of T2DM for South Asians in the Greater Houston Area. Participants' responses revealed concerns about cost, usability, and effectiveness, alongside clear preferences for less intrusive biosensor models such as wristbands, glasses, and skin patches over implants or mouthguards.

These insights highlight important implications for both researchers and device designers. Future studies should further explore how cultural perceptions of illness visibility, stigma, and family influence shape technology adoption among South Asians and other immigrant communities. For device developers, these findings suggest that discreet, affordable, and user-friendly biosensors are more likely to be accepted in this population, particularly when designs minimize social visibility and align with cultural values around privacy and resilience. Implications.

IMPLICATIONS

This research provides a foundation for strategies to improve Type 2 diabetes management among South Asians in the United States. The findings emphasize the importance of accounting for cultural norms and stigma when developing health interventions. Fear of being

judged can cause many South Asians to feel uneasy discussing their T2DM status in public, making discreet, culturally attuned tools essential. Health-focused strategies could include biosensor awareness workshops hosted at temples, mosques, or churches, multilingual educational materials distributed in community clinics, and community-based support programs that integrate traditional dietary practices with medical guidance. Such culturally sensitive approaches would ensure that biosensor adoption is not only technically feasible but also socially acceptable within South Asian communities.

These findings highlight the need for biosensors that are discreet, affordable, and user friendly in the business and product development perspective. Participants showed strong preferences for wristbands, glasses, and skin patches over implants or mouthguards, reflecting the importance of minimizing device visibility and reducing social stigma. By incorporating these design preferences, companies can better tailor their products to the needs of South Asian populations and other culturally diverse groups. This strategy enhances health equity while simultaneously improving market penetration and sustainability for biosensor technologies.

LIMITATIONS

The sample size for this study was smaller than anticipated, with only 17 qualifying participants. This reflects the difficulty of recruiting individuals willing to discuss Type 2 diabetes, a condition that carries cultural stigma in many South Asian communities. Because of the limited sample size, statistically significant conclusions cannot be drawn, and the findings should be interpreted as exploratory rather than definitive. Future research could increase statistical power by expanding recruitment beyond the Greater Houston Area—such as coordinating cross-state or multi-region surveys—to capture a larger and more diverse South Asian population.

Additionally, the use of a voluntary response survey introduces potential self-selection bias, as those who chose to participate may hold stronger views, higher health literacy, or greater willingness to discuss T2DM than the broader population. The geographic scope of the sample— South Asians with T2DM in the Greater Houston Area—further limits generalizability, as cultural dynamics may differ across U.S. regions and within South Asia itself. Moreover, this study assessed perceptions of biosensors rather than actual device use, meaning that performance, usability, and long-term adherence could not be evaluated.

Despite these limitations, the study provides valuable preliminary insights into how stigma, cultural attitudes, and device visibility influence biosensor acceptance.

These findings can serve as a foundation for future research, which should recruit larger and more diverse samples, partner with clinics or community organizations to improve participation, and incorporate trials of actual biosensor devices to validate self-reported perceptions.

CONCLUSION

Future studies should build on these findings by recruiting larger and more diverse samples of South Asians across the United States, incorporating clinic-based recruitment to minimize bias, and testing biosensors in real-world use to assess both perceptions and performance. Expanding this work to include other immigrant populations would also help clarify how cultural norms shape technology adoption across contexts.

The insights from this study emphasize that T2DM management tools will only succeed if they are designed and implemented with cultural sensitivity. For clinicians and public health professionals, this means prioritizing interventions that reduce stigma and provide education in linguistically and culturally accessible ways. For policymakers, the findings underscore the need to support programs and insurance structures that make emerging biosensor technologies affordable and accessible to underserved immigrant populations. For developers, the results point toward clear design priorities: biosensors that are discreet, user-friendly, and aligned with community preferences are more likely to be embraced.

Taken together, this multidisciplinary approach holds the potential to transform diabetes care, not only improving glycemic control and quality of life for South Asians with T2DM but also offering broader lessons for managing chronic conditions in diverse cultural settings.

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Appendix A: The structure and questions of the survey

AP Research Study: Type 2 Diabetes and Biosensors
I am conducting a research study on Type 2 diabetes in the South Asian community of the Greater Houston Area and would appreciate it if you could answer the following questions for my research. Thank you.
Indicates required question

You are invited to participate in a research project about Type 2 Diabetes management. This online survey should take about 5–10 minutes to complete. Participation is voluntary, and responses will be kept anonymous and/or confidential to the degree permitted by the technology being used. You have the option to not respond to any questions that you choose. Submission of the survey will be interpreted as your informed consent to participate. (I understand and I wish to proceed. I consent to participating in this study / I DO NOT wish to proceed. I DO NOT consent to participating in this study.)

Requirements

Are you of South Asian origin? (India, Pakistan, Bangladesh, Nepal, Bhutan, Sri Lanka, Maldives) (Yes/No)
Would you say you live in the Greater Houston Area? (Harris, Fort Bend, Montgomery, Brazoria, Chambers, Galveston, Liberty, Waller) (Yes/No/Other)
Do you have Type 2 Diabetes? (Yes/No)

Demographics

How old are you? (Your answer)
How long have you had Type 2 diabetes? (<1 year; 1 year; 2–5; 6–10; 11–15; 16–20; 21–25; 26–30; 31–35; 36–40; 41–45; 46–50; 51–55; 56–60; 60+ years)
Please list all medication you take for Type 2 diabetes: (Your answer)
How long have you been the medication listed above? (Your answer)
What is your last A1C level? (Your answer)
How often do you check your blood glucose with glucometer per day? (0–6+ times)
What is your average blood sugar mg/dL per week? (Your answer)

Perceptions and Attitudes

Do you follow a diet for your diabetes? (Yes/No/Other; elaborate if yes)
Do you try natural remedies and treatments? (Yes/No/Other; elaborate if yes)

(Type 2 diabetes is not life-threatening; Glucometers are not accurate; Sufficient provider information is given; Diabetes causes anxiety/stress; Diabetes causes physical discomfort and limits activities)
(Strongly disagree / Disagree / Neutral / Agree / Strongly agree)

What other personal beliefs influence your decision-making? (Your answer)

Introduction into Biosensors

Have you heard of biosensors? (Yes/No)
If so, what do you know? (Your answer)

Biosensors

Biosensors are analytical devices that combine a biological component with a physicochemical detector to convert a biological response into a measurable signal.

Scale: (1 = definitely use; 2 = might use; 3 = do not care; 4 = will not use; 5 = definitely not use)

Wristband: Bluetooth-enabled, non-invasive sweat monitoring (glucose, temperature, sodium, potassium, lactate). (1–5)
Mouth guard: Saliva-based metabolite sensing using enzymatic electrode and peroxide detection. (1–5)
Skin patch: Microneedle interstitial fluid monitoring (up to 72 hours, minimal invasion). (1–5)
Glasses: Sensor-integrated eyewear measuring sweat analytes with Bluetooth data transmission. (1–5)
Implant: Subdermal device using graphene oxide and enzymatic sensing via small incision. (1–5)

Which one are you most likely to use? (Wristband/Mouthguard/Glasses/Skin Patch/Implant)

Biosensors Advances and Challenges

(Biosensors are costly/ineffective; Biosensors are inaccurate; Biosensors cause physical/social discomfort)
(Strongly disagree / Disagree / Neutral / Agree / Strongly agree)

Classification of Variable Stars Using Machine Learning Models

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ABSTRACT

This study explores the application of machine learning models—Random Forest, K-Nearest Neighbors (KNN), and XGBoost—to classify variable stars in the Optical Gravitational Lensing Experiment (OGLE) dataset using five features: the period of variation, V-I band color index, I-band amplitude or main eclipse depth, the mean or maximum V-band magnitude, and the mean or maximum I-band magnitude. The brightness variations of variable stars provide insights into stellar evolution and structure. However, their classification poses challenges due to noisy data and class imbalances. Following our data preprocessing, our Random Forest model achieved the highest accuracy of 96.55%. XGBoost performed similarly with 96.50% accuracy, though it showed signs of overfitting on majority classes. The KNN model also performed well with an accuracy of 95.78% but struggled with class imbalance. Confusion matrices for all three models revealed similar misclassifications between underrepresented star types, such as Heartbeat stars and eclipsing binaries. Our research demonstrates that machine learning models can efficiently classify variable stars on a large-scale, offering advantages over traditional methods.

INTRODUCTION

Variable stars undergo brightness fluctuations over time, providing key insights into stellar structure and evolution (Sherwood & Plaut, 1975). They are classified as intrinsic variables, which fluctuate due to internal processes like pulsations, and extrinsic variables, which vary due to external factors like eclipses in binary systems. Further classification is based on properties such as periodicity, amplitude, and spectral characteristics (Percy, 2007).

Historically, variable star classification has relied on manual inspection, which is time-intensive and prone to human error. With the growth of large astronomical surveys like OGLE-IV (OGLE Collaboration, 2022), efficient and accurate classification methods are essential. Machine learning serves as a powerful tool for automating this process.

In this study, we address issues of class imbalance, missing data, and compare the performance of three widely used machine learning models in astronomical classification—Random Forest, K-Nearest Neighbors (KNN), and XGBoost—in classifying variable stars from the OGLE-IV catalog.

DATA ANALYSIS & METHODOLOGY

We extracted our variable star data from the fourth edition of the Optical Gravitational Lensing Experiment (OGLE-IV). The OGLE-IV database contains information on over 740,000 variable stars across 9 types: Cepheids, Delta Scuti stars, eclipsing binaries, RR Lyrae stars, Long-period variables, anomalous Cepheids, type II Cepheids, transiting planets, and Heartbeat stars.

To prepare the OGLE-IV dataset for analysis, we first addressed missing values. Placeholder entries (-99.99) were converted to NaNs (short for "Not a Number," a standard marker used in data analysis to represent missing or invalid values) to ensure statistical calculations were not skewed by arbitrary values. Columns with over 25% missing data (such as A_2, the I-band amplitude of the second periodicity) or minimal relevance to variability type (e.g., identifiers, positional coordinates, and subtype labels) were removed. We retained five key features: period of

variation (P_1), V-I band color index (V_I), I-band amplitude or main eclipse depth (A_1), the mean or maximum V-band magnitude (V), and the mean or maximum I-band magnitude (I). Missing values were imputed using the median for each variability type. Due to the lack of anomalous Cepheid instances, we considered consolidating them with classical Cepheids and therefore calculated the Euclidean distance between the two groups to assess their similarity. Based on our findings, we proceeded with their consolidation, as the median distance of 3.07 and mean distance of 4.15 were significantly smaller than the distances between Cepheids and other variable stars.

The dataset also exhibited severe class imbalance, with eclipsing binaries and RR Lyrae stars making up over 80% of the data, while transiting planets and Heartbeat stars accounted for just 0.07%. To mitigate this imbalance, we applied the Synthetic Minority Oversampling Technique to oversample the minority classes by generating synthetic samples based on K-Nearest Neighbors (Chawla et al., 2011). To mitigate the risks of overfitting, we used RandomUnderSampler to undersample eclipsing binaries and RR Lyrae stars to create a more balanced dataset.

We trained the Random Forest model using Python's Scikit-learn library, splitting the dataset into 66% training and 33% testing with 100 decision trees, which yielded a 96.55% accuracy score (Pedregosa et al., 2011). Although increasing the number of trees beyond 100 can reduce variance, our results showed that accuracy and performance gains plateaued past this point. Using 100 trees, therefore, provided the best balance between performance and computational efficiency. Feature importance analysis showed that P_1 and V_I were the most influential features, contributing 38.1% and 33.6% to model decisions, respectively.

Given the feature similarity between variable star classes, we also explored the KNN model for its ability to capture local patterns and distinguish between similar classes. After testing different k values, we found that 7 neighbors provided the best accuracy, as smaller k values led to unstable decision boundaries and overfitting, while larger k values reduced accuracy. Our rebalancing techniques, coupled with the use of a stratified tenfold cross-validation approach, helped us ensure balanced training across all classes. We chose ten folds because it is widely considered a standard that balances bias and computational time. This configuration of hyperparameters achieved an accuracy of 95.78%. An analysis of variance (ANOVA) test revealed that P_1 was the most influential feature, as its removal dropped the model's accuracy to 87.59%. A_1 had the second largest impact, reducing accuracy to 94.20% when excluded. Other important features, including V_I, V, and I, each contributed to a slight decline in performance, lowering accuracy by approximately 1%.

Lastly, we selected the XGBoost model due to its ability to handle missing values efficiently and leverage parallel processing, making it well-suited for our large dataset. The data was split into 66% training and 33% testing sets, and we used multiclass logarithmic loss (mlogloss) as the evaluation metric. This choice ensured that the model not only rewarded correct predictions but also penalized confidently incorrect ones, which was important for distinguishing between variable star classes with very similar features. After applying data rebalancing, the model achieved an accuracy score of 96.50%. An ANOVA test revealed that P_1 and A_1 were the strongest contributors to classification, as their removal dropped the accuracy to 88% and 95%, respectively, while removing I, V, and V-I decreased accuracy by only about 0.5%.

RESULTS

The Random Forest classifier demonstrated strong performance for the majority classes--Delta Scuti stars, eclipsing binaries, long period variables, and RR Lyraes--with F1-scores between 0.95–1.00. However, underrepresented classes like Heartbeat stars (F1-score: 0.69) and type II Cepheids (0.75) had lower recall, meaning the model frequently misclassified these stars as other types rather than correctly identifying them. The KNN model performed similarly, excelling in well-represented categories while facing challenges with minority classes, particularly Heartbeat stars, type II Cepheids, and transiting planets, where recall dropped significantly (F1-scores: 0.54, 0.67, and 0.40, respectively). Compared to these models, XGBoost maintained high precision and recall for dominant classes but showed improvements in Heartbeat stars, type II Cepheids, and transiting planet classification (F1-scores: 0.59, 0.73, and 0.83, respectively), with transiting planets benefiting from a significant boost in recall and precision. While some misclassifica-

tion persists, these results suggest that XGBoost is better at distinguishing underrepresented variable types than the previous models, making it a more balanced approach despite the data's inherent class imbalance.

The Random Forest model demonstrated strong performance, achieving over 90% accuracy across most classifications. However, it struggled to distinguish Heartbeat stars and type II Cepheids from eclipsing binaries, misclassifying approximately 35% and 27% of these stars, respectively. Similarly, the KNN model maintained high classification accuracy, effectively capturing patterns among most variable stars while performing comparably to the Random Forest model. However, in addition to Heartbeat stars and type II Cepheids, a high proportion of transiting planets were also misclassified as eclipsing binaries. The XGBoost model exhibited robust performance, excelling in identifying transiting planets and most intrinsic variables with high precision. However, like the other models, it struggled to distinguish Heartbeat stars and type II Cepheids from eclipsing binaries. The consistency of these results suggests that misclassification stems less from the models themselves and more from underlying class imbalance, where the overrepresentation of certain types leads to strong performance in majority classes but leaves minority types more prone to error.

DISCUSSION

Reflection:

Our research highlights the potential of machine learning models—Random Forest, KNN, and XGBoost—in classifying variable stars with high accuracy. However, the misclassification of minority classes indicates the need for refined techniques. Possible improvements include incorporating additional features like light curve images and multi-wavelength data to enhance model performance. Deep learning approaches, such as dense neural networks, could further improve classification, especially for underrepresented star types. Applying these models to ongoing surveys like ASAS-SN will help refine classification frameworks and contribute to the discovery of new variable star types. As astronomical datasets grow, integrating machine learning into stellar classification will be essential for advancing our understanding of stellar behavior and evolution.

ACKNOWLEDGEMENT

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Figure 1: Heat Map showing F1-Scores for Random Forest, KNN, and XGBoost.

Identification and Validation of CHD1L's Partners During Neurodevelopment

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ABSTRACT

Autism Spectrum Disorders (ASD) are characterized by restrictive and repetitive behaviors, as well as deficits in social interactions and communication. A variety of genetic mutations and environmental factors contribute to the heterogeneity of ASD phenotypes. Among the many genetic alterations associated with ASD, copy number variations (CNVs) in the 1q21.1 region are the second most common CNVs linked to ASD. The protein CHD1L (Chromodomain helicase DNA-binding protein 1-like), a chromatin remodeler, is a candidate gene to explain the mirrored phenotypes caused by duplications and deletions in the 1q21.1 region. Recent data from the Golzio lab indicates that CHD1L plays a role in neurodevelopment in mice and zebrafish. This study identifies and validates an interaction between CHD1L and neurodevelopmental transcription factors EGR2 and SOX2 using co-immunoprecipitation and Western blot. Together, these findings suggest that CHD1L may participate in neurodevelopment through interactions with key transcription factors, providing a foundation for future studies of its role in ASD.

INTRODUCTION

i. Autism Spectrum Disorders

Autism spectrum disorders (ASD) are a heterogeneous group of developmental disorders that are characterized by two main criteria: a persistent deficit in communication and social interaction across multiple contexts and patterns of restricted and repetitive behaviors, activities, and interests [1]. In 2022, the American Psychiatric Association published the DSM-5-TR, a revision of the 2013 DSM-5 that clarified the diagnostic criteria for ASD. These five new criteria are: persistent deficits in social communication and interactions; restrictive and repetitive patterns of behavior, interests, or activities; symptoms that are present in the early developmental period; symptoms that cause significant impairment in social, occupational, or other important areas of functioning; and that all these disturbances are not best explained by intellectual disability or global developmental delay. ASD occurs more frequently in males than females, and approximately 4 males are diagnosed for every 1 female [16]. ASD is also marked by several comorbidities, such as attention deficit disorder with or without hyperactivity (28%), bipolar disorder (5%), and schizophrenia (4%) [17].

ASD also has neurological comorbidities such as changes in the development of the cortex, which present as microcephaly and macrocephaly, as well as changes in the hippocampus and cerebellum [9, 18]. Symptoms of autism spectrum disorders are typically seen at ages one and two, an important period for the development of the hippocampus, which is involved in memory, spatial reasoning, and social interactions - abilities that are impacted by ASD [9]. The cerebellum is traditionally known for its primitive role in motor learning and coordination, but can also communicate with cortical neurons to help them mature during neurodevelopment. Additionally, the cerebellum plays a large role in cognitive processing and social behavior, and there is evidence that it is also involved in ASD. In fact, it is the neural structure most often found to be abnormal in ASD [10]. Many ASD-related genes show strong co-expression in the cerebellum, including SHANK2 and SHANK3, TSC1 and TSC2, and AUTS2, among others [12]. Support for this role also comes from evidence that cerebellar hemorrhages or lesions occurring soon after birth increase the incidence and risk of ASD. Therefore, there may be a developmental

window during which the cerebellum plays a central role in the acquisition of cognitive functions and social skills [12].

ii. The Genetics of ASD

The genetic component of ASD is highly variable. Different mutations and environmental factors cause the variety of ASD phenotypes. There is a strong genetic component to ASD, as concordance for the diagnosis of ASD in monozygotic twins is 90% and 30% for dizygotic twins, respectively [12]. Genetic mutations known to be linked to ASD are either point mutations, as in the CHD8 and SHANK3 genes, or copy number variants (CNVs), Wwhich are duplications or deletions of a large fragment of a chromosome [19, 20]. CNVs are often flanked by low copy repeats (LCRs), or blocks of DNA ranging in size from 1 to 400 kb and present at several points in the genome [13]. LCRs promote non-allelic homologous recombination (NAHR) and misalignment of directly oriented sister chromatids. NAHR generates both duplications and deletions, which in turn give rise to copy number variation [13]. Of the twenty or so CNVs known to occur in populations diagnosed with ASD, deletions and duplications of the distal 1q21.1 region are the second most common, after those of 16p11.2 [15]. There are two classes of CNVs associated with the 1q21.1 region. Class I duplications and deletions of the distal region, delimited by breakpoints BP3 and BP4, which do not include the proximal thrombocytopenia absent radius region (TAR), mutations of which are associated with low platelet count and absence of radius bone. Class II CNVs include the TAR region [14]. The focus of this study is on class I 1q21.1 CNVs, which affect up to 13% of people with ASD associated CNVs. Distal 1q21.1 CNVs have mirrored phenotypes - deletions of this region cause autism, schizophrenia, microcephaly, and small body size, and duplications cause ASD, macrocephaly, and large body size. We want to better understand the mechanism affected by CNVs in this region, and which gene or genes are responsible for these mirror phenotypes.

The distal 1q21.1 region contains eight genes: PRKAB2, FMO5, BCL9, ACP6, GJA5, GJA8, GPR89B, and CHD1L [20]. PRKAB2 is a gene whose mutation has been associated with a cohort of individuals with schizophrenia [21]. FMO5 encodes Flavin Containing Dimethylaniline Monooxygenase 5, which mediates the N-metabolic oxidation of diet-derived trimethylamine (TMA), associated with trimethylaminuria or fishy smell syndrome [22]. Common variations in the BCL9 gene confer a risk of schizophrenia and may also be associated with bipolar disorder and major depressive disorder [23]. ACP6 codes for lysophosphatidic acid phosphatase type 6, high levels of which can lead to ovarian cancer [24]. GJA5 has been identified as the gene responsible for the phenotypes seen in congenital heart disease of the 1q21.1 region [25]. Pathogenic variants of GJA8 have been identified in patients with various developmental eye disorders [26]. GPR89B enables voltage-dependent anion channel activity [27].

When Lemée, Loviglio, et al., duplicated each of the eight genes in the distal 1q21.1 region in Danio rerio (zebrafish), they found that only CHD1L caused a significant increase in brain size (macrocephaly) [28]. A subsequent study showed that deletion of CHD1L caused a significant decrease in brain size (microcephaly). In this study, CHD1L function was disrupted with N-ethyl-N-nitrosourea (ENU) and zebrafish were photographed 5 days after fertilization. They were compared to zebrafish with a duplication of CHD1L (via microinjection) and a control group. This comparison revealed the same mirrored phenotype seen in humans with deletions or duplications of the distal 1q21.1 region. These results were further confirmed by Lemée, Loviglio, et al. in a study on mice. Mouse embryos were electroporated with either an empty vector as a control, CHD1L complementary DNA (cDNA) for overexpression, or endogenous small interfering RNA (esiRNA) targeted against CHD1L to mimic deletion. Effects on brain regions involved in neurogenesis - the ventricular zone (VZ), subventricular zone (SVZ), and cortical plate (CP) - were analyzed by immunofluorescence. Overexpression of CHD1L cDNA significantly increased the proportion of cells expressing T-box transcription factor 1 (Tbr1), a marker for mature neurons, compared with controls. This indicates that CHD1L overexpression promotes neurogenesis. Additionally, deletion of CHD1L caused a decrease in the number of Tbr1+ cells, and hence fewer mature neurons in the CP.

iii. CHD1L and Preliminary Studies

CHD1L, or Chromodomain helicase DNA-binding protein 1-like (figure 1), is a chromatin remodeler that

uses energy from ATP hydrolysis to reposition or restructure nucleosomes. It is also involved in DNA repair and regulation, particularly in response to DNA damage. It responds to damage via its partner, poly (ADP-ribose) polymerase 1 (PARP1). When DNA damage occurs, PARP1 auto-PARylates, or adds polyADP-ribose (PAR) groups to itself. This allows CHD1L to bind to PAR with its macro domain and make DNA accessible for transcription or other cellular processes by rearranging the structure of chromatin [34].

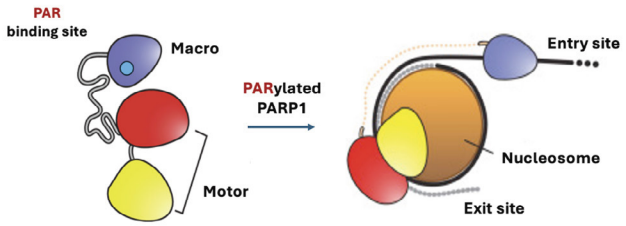
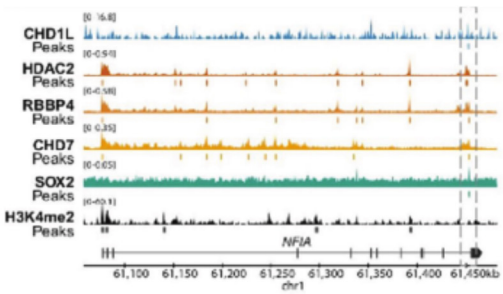


Figure 1. Lehmann et al., (2017) Molecular Cell.

The CHD1L protein consists of three lobes: a macro domain containing the PAR-binding site, a C-terminal ATPase, and an N-terminal ATPase. The C-terminal ATPase domain helps hydrolyze ATP to generate the energy needed to reposition nucleosomes. The N-terminal ATPase domain functions together with the C-terminal ATPase domain, presumably assisting binding and interaction with nucleosomes [34].

CHD1L is also known to be involved in pluripotency in mice and cell models, and in Congenital Anomalies of the Kidneys and Urinary Tract (CAKUT) syndromes, a developmental syndrome affecting the kidneys and urinary tract [29, 30]. Beyond these contexts, the function of CHD1L in development remains largely unknown. The goal of this project is therefore to find and confirm the partner proteins of the CHD1L protein to better understand this role. To this end, Lemée, Loviglio, et al. carried out studies on wild-type and CHD1L-deleted human neural progenitor cells (hNPCs) (CHD1L -/-). RNA sequencing (RNA-seq) was performed comparing two lines with CHD1L -/- and a wild-type line, where 304 overexpressed and 608 underexpressed genes were found, including Dipeptidyl Peptidase Like 6 (DPP6) and Unc-5 Netrin Receptor D (UNC5D), two genes with important roles in neurodevelopment. An Assay for Transposase Accessible Chromatin and Sequencing (ATAC-seq) was performed in wild-type and CHD1L -/- hNPCs, showing that, compared to the control, where chromatin is open and accessible, there is a clear reduction in accessibility in both CHD1L -/- lines for the UNC5D and DPP6 genes. These results were confirmed with RNA-seq, where expression of UNC5D and DPP6 is significantly reduced in both CHD1L deletion lines. Immunoprecipitation with anti-CHD1L antibodies was then performed on wild-type and CHD1L -/- hNPCs. Mass spectrometry was then performed on the resulting proteins. The list of proteins present in the sample obtained by mass spectrometry was analyzed with Search Tool for the Retrieval of Interacting Genes/Proteins (STRING). To support these results, a Cleavage Under Target and Release Using Nuclease (CUT&RUN) comparison was also carried out.

This comparison was carried out on the Nuclear Factor 1A (NFIA) gene, which is involved in neurodevelopment [27]. Figure 2 shows that all these proteins are present at the same chromatin location at the same time in this active gene. These results support our hypothesis that CHD1L plays a role in neurodevelopment and neurodevelopmental disorders, possibly in connection with the NuRD complex, and may cause the mirror phenotypes



seen in human 1q21.1 CNV syndromes.

Figure 2. Lemée, Loviglio et al. (2025) Nucleic Acids Research.

iv. CHD Family and NuRD Complex

CHD (chromodomain helicase DNA binding) chromatin remodelers are frequently associated with neurodevelopmental disorders and are often linked to the Nucleosome Remodeling and Deacetylase Complex (NuRD), which is involved in neuronal differentiation and development. As seen in figure 3, CHD proteins are mainly divided into three subfamilies according to their specific domains:

subfamily I, which has a basic chromodomain and an ATP-dependent sucrose non-fermentable 2 (SNF2) helicase domain; subfamily II, which contains an additional PHD zinc finger domain; and subfamily III, which includes an additional SANT and BRK domain.

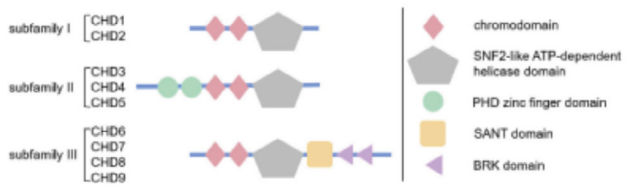


Figure 3. Guo, Gong et al., (2021) Frontiers.

SANT is a protein domain that enables many chromatin remodeling proteins to interact with histones. The BRK domain has an unknown function, but is often found in proteins involved in transcription and developmental signaling in higher eukaryotes, particularly in proteins that remodel chromatin [32]. Mutations in genes encoding chromatin remodelers are over represented in cohorts of neurodevelopmental disorders, suggesting that epigenetics is a converging pathogenic pathway between these disorders [5]. According to SFARI GENE, a database for autism research, CHD1, CHD2, CHD3, CHD7, and CHD8 have been associated with ASD. SFARI has a genetic scoring system that considers any evidence that may support the relevance of a gene in ASD and places each gene in a category based on the amount of that evidence. The highest category is "syndromic", which means that the mutation is associated with a substantial degree of risk and is consistently associated with the features that are necessary for the diagnosis of ASD. The category just below syndromic is category one, which means that the mutation is clearly implicated in ASD, typically by the presence of at least three probable "de novo" mutations reported in scientific literature. The next category, category two, means that there are at least two probable "de novo" mutations implicated in autism reported in scientific literature. Mutations in the CHD2-3, 7, and 8 genes all have a category one score, and CHD1 is a category two, so there is strong evidence that the CHD family is linked with ASD.

Because many ASD-associated genes, including members of the CHD family, encode proteins that regulate chromatin structure, disruptions in epigenetic control provide a plausible mechanistic link between genetic mutations and altered neurodevelopment. Chromatin remodeling is particularly important in the context of ASD because it influences how genes involved in brain development are expressed. In eukaryotic cells, nuclear DNA is packaged with histones to form chromatin, which can adopt either an open (transcriptionally active) or closed (transcriptionally inactive) configuration, thereby controlling the accessibility of transcription factors to their binding sites. These chromatin states are regulated by epigenetic mechanisms, including post-translational modifications of histone tails and DNA modifications such as methylation. Together, these interacting processes enable precise spatial and temporal control of gene expression during development, and growing evidence implicates dysregulation of epigenetic factors in the onset and progression of neurodevelopmental and psychiatric disorders [8].

By altering the epigenetic state of genes or histones, chromatin remodelers play a central role in the machinery that translates external signals into lasting changes in gene expression patterns [14]. Moreover, chromatin remodelers are multifunctional proteins that can influence various processes along the developmental continuum, including the generation and specification of neural progenitors, differentiation and expansion of cell types, migration and circuit integration [5]. Together, these observations lead us to hypothesize that CHD1L contributes to human neurodevelopment and neurodevelopmental disorders, potentially through interactions with the NuRD complex, thereby contributing to the mirrored phenotypes observed in 1q21.1 CNV syndromes.

METHODS

i. Cell seeding and Transfection

Prior to transfection, 1 × 10^6 Human Embryonic Kidney 293 Epstein-Barr Virus Nuclear Antigen (HEK 293 EBNA) cells were seeded per well in 2 mL of Dulbecco's Modified Eagle Medium (DMEM; 1 g/L glucose) supplemented with 10% Fetal Bovine Serum (FBS 8407), and gentamicin. To determine cell concentration, a 1:10 dilution of the cell suspension from the flask was prepared, and 100 µL of this diluted suspension was mixed with 100 µL of Trypan Blue, resulting in a final 1:2 dilution for

counting.

For each transfection condition, two tubes were prepared. The first tube contained 50 µL of Opti-MEM and 1 µg of plasmid DNA; when two protein partners or three plasmids were transfected simultaneously, a total of 1.5 µg of plasmid DNA was used. The second tube contained 50 µL of Opti-MEM and 5 µL Lipofectamine 2000. Both tubes were vortexed and incubated for 5 minutes. The diluted plasmid DNA was then added to the Lipofectamine-containing tube, gently mixed, and incubated for at least 10 minutes to allow complex formation. The mixture was briefly centrifuged before being added dropwise to the cells.

ii. Protein Extraction

Cold Radioimmunoprecipitation Assay Buffer (RIPA) lysis was prepared with one Protease Inhibitor Cocktail (PIC) per tube +1 (400 µL/condition). RIPA buffer contained: 2.5 mL 1M Tris-HCl, pH 8 (50 mM), 1.5 mL 5M NaCl (150 mM), 250 µL Triton X-100 (0.5%), and H2O mQ qsp 50 mL (45.75 mL). Medium was removed and cells were washed with 2 mL sterile PBS per well. 400 µL per well of cold RIPA buffer and 1x PIC were added directly to the cell surface and the plates were gently tapped to loosen the cells, which were then incubated for 30 minutes at 4 °C.

The cell lysate from each well was transferred to its corresponding microtube and kept on ice. Samples were then sonicated for 1 minute (cycle 0.6, 40% amplitude). Following sonication, 1µL of RNase-free DNase was added to each sample, mixed thoroughly, and incubated on ice for 30 minutes. The samples were then centrifuged at 15,000 rpm for 30 minutes at 4 °C. The resulting supernatant was transferred to a clean tube and stored at -80 °C if not used immediately for immunoprecipitation.

iii. Co-Immunoprecipitation

Magnetic beads were vortexed for at least 30 seconds before transferring 10 µL of beads per IP into a micro-tube. Beads were washed three times with 800 µL of cold RIPA buffer. After removing the RIPA buffer and adding 100 µL of cold RIPA + PIC 1x per IP, they were mixed and separated 100 µL each into an annotated reaction tube. Afterwards, 300 µL of protein lysate is added to the beads with RIPA/PIC1x and incubated overnight at 4 °C on a spinning wheel.

iv. Western Blot

For Western blot input preparation, 10 µL of protein lysate was mixed with 5 µL of 4x Laemmli SDS sample buffer. The mixture was incubated at 95 °C for 3 minutes, briefly centrifuged, and stored at 4 °C if not used immediately for Western blotting. On the following day, immunoprecipitation beads were washed three times with 400 µL of cold RIPA buffer. After removal of the final wash, 20 µL of 2x Laemmli buffer was added to the beads.

The beads in the buffer were heated for 10 minutes at 95 °C, then centrifuged and kept at -20 °C until it was time to start the Western blot. The gel for SDS-PAGE is a resolving gel containing: 2 mL H2O mQ, 1.7 mL 30% Acrylamide mix, 1.3 mL 1.5 M Tris-HCl pH 8.8 resolving gel buffer, 25 µL 20% SDS, 50 µL 10% APS, and 5 µL pure TEMED.

After adding APS and TEMED, the gel was quickly placed in 2 glass plates and covered in ethanol for at least 20 minutes to avoid contact with air and to ensure good polymerization quality. The stacking gel (4% 2 mL) contains: 1.44 mL H2O mQ, 0.27 mL 30% Acrylamide mixture, 0.25 mL 0.5 M Tris-HCl pH 6.8 stacking gel buffer, 10 µL 20% SDS, 10 µL 10% APS, and 2 µL TEMED. After about 20 minutes, the ethanol was removed, the stacking gel inserted, and the comb added. The mold was filled with 1x Tris-Glycine stacking gel. 3 µL ladder, 15 µL input, and 15-20 µL IP were loaded.

Gel electrophoresis ran for 10 minutes at 100 V or until the proteins were in the resolving gel and about 20 minutes at 200 V. Transfer buffer (0.5x) contained: 50 mL 10x Western blot buffer, 150 mL ethanol, and 1 liter H2O mQ qsp. The transfer buffer is 0.5x and contains 10x Western blot buffer, ethanol, and water mQ qsp. Protein transfer was performed for 1h15 at 100V. The membrane was then incubated in 5% milk dissolved in TBS-T. TBS-T contains 1x Tris-buffered saline and 0.1% Tween 20.

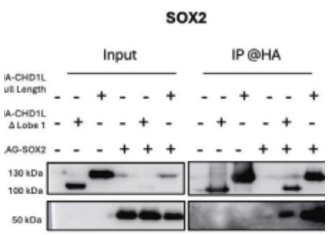
For immunostaining, the primary antibodies were first diluted in 5% milk in TBS-T and incubated overnight at 4 °C. Rabbit anti-HA and rat anti-Flag antibodies were used. Secondary antibodies were also diluted in 5% milk in TBS-T and incubated for one hour at room temperature and shaken. These were anti-rabbit and anti-rat antibodies.

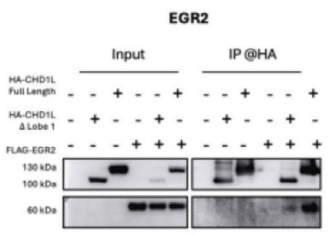
RESULTS

i. CHD1L and EGR2

To determine whether CHD1L interacts with EGR2, a Western blot analysis was performed after co-immunoprecipitation. Two versions of CHD1L were tested: the "long" version, containing all three lobes, and the "short" version, lacking the N-terminal ATPase domain (the yellow lobe in figure 1). Both CHD1L variants were tagged with HA, while EGR2, the protein of interest, was tagged with FLAG.

Cell lysates were immunoprecipitated with an anti-HA antibody, and interactions were validated by Western blot with anti-HA and anti-FLAG antibodies. As shown in figure 4a, a band at around 60 kDa, corresponding to EGR2, was detected in samples immunoprecipitated with





CHD1L. This result confirms an interaction between CHD1L and EGR2.

Figure 4a *Figure 4b*

The presence of both versions of CHD1L was confirmed in the input on the left (figure 4a) by an anti-HA antibody, with strong bands observed at around 130 kDa for the long version and 100 kDa for the short version. The presence of EGR2 was also confirmed by FLAG antibody in the input.

Interaction between CHD1L and EGR2 was observed for both versions of CHD1L, with bands detected at around 60 kDa for EGR2 and at around 130 kDa (long version) and 100 kDa (short version) for CHD1L. No significant difference in intensity was observed between the two versions of CHD1L in this experiment.

ii. CHD1L and SOX2

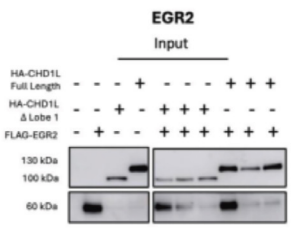
To determine whether CHD1L also interacts with SOX2, we followed the same approach as that used for EGR2. Two variants of CHD1L, one "long" including the three lobes and the other "short" without the N-terminal ATPase domain, were studied. Both variants were tagged with HA, while SOX2 was tagged with FLAG.

After co-immunoprecipitation of cell lysates using an anti-HA antibody, interactions were analyzed by Western blotting with anti-HA and anti-FLAG antibodies. As shown in figure 4b, a band corresponding to SOX2 (~45 kDa) was detected in samples containing CHD1L, indicating an interaction between these two proteins. In addition, detection of the long (~130 kDa) and short (~100 kDa) variants of CHD1L was confirmed by anti-HA antibody and EGR2 by anti-FLAG antibody in the input.

The interaction between CHD1L and SOX2 was detected for both versions of CHD1L, with a band corresponding to SOX2 (~45 kDa). Bands of both versions of CHD1L, at ~130 kDa for the long version and 100 kDa for the short version, are also visible. The signal of SOX2 seems slightly more pronounced with a 5:1 ratio in this experiment.

iii. Optimization

When we observed the weak signal of short CHD1L in our first Western blots we decided to test several ratios of SOX2 and EGR2 to CHD1L to eliminate a competition between the two proteins as a potential cause. Without performing co-immunoprecipitation, we tested the inputs of SOX2 and EGR2 with the two versions of short CHD1L, using ratios 3:1, 5:1, and 10:1 (potential partner proteins: CHD1L).



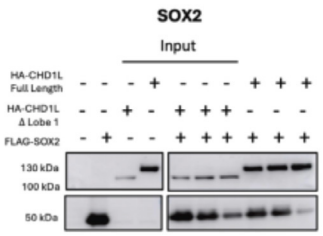
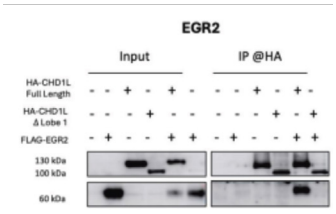


Figure 5a *Figure 5b*

In figures 5a and 5b, the columns on the right side show these three ratios: the first three columns with the short version of CHD1L, and the last three columns with the long version. We chose the 3:1 ratio as optimal to observe a strong presence of EGR2 and short CHD1L, because in figure 5a, in the fifth and eighth columns, their signal is the most pronounced. We then performed a co-im-

munoprecipitation with this ratio and observed a stronger presence of EGR2. However, the presence of short CHD1L remained weak, and we did not reconfirm the interaction between CHD1L and EGR2.

In figure 5b, we see that the strongest signal of SOX2





with short CHD1L is obtained with a ratio of 5:1. We therefore performed a co-immunoprecipitation with this ratio (figure 6b) and observed an improvement in the presence of both proteins, despite high background noise in the Western blot.

Figure 6a ***Figure 6b***

Our tests with different ratios allowed us to optimize the experimental conditions to detect interactions between CHD1L and its protein partners, in particular SOX2 and EGR2. The results show that the interaction signal varies depending on the ratio used, with a stronger signal observed at a ratio of 3:1 for EGR2 and 5:1 for SOX2. These observations suggest that the relative abundance of partner proteins influences the efficiency of co-immunoprecipitation and thus the detection of the interaction. This type of optimization is essential to avoid potential competition between protein partners and ensure the reliability of the results. These data support the presence of specific interactions, though additional analyses are needed due to sometimes weak signals for short CHD1L.

DISCUSSION

SOX2 is a pioneer transcription factor involved in the maintenance of pluripotency in embryonic and neuronal stem cells and is also part of the NuRD complex. The NuRD (Nucleosome Remodeling and Deacetylase) complex plays a crucial role in neurodevelopment by participating in chromatin remodeling and gene regulation. This complex combines ATP-dependent nucleosome remodeling and histone deacetylation activities, allowing it to modulate chromatin accessibility and regulate transcription [33]. The role of NuRD in neurodevelopment is particularly significant in embryonic stem (ES) cells and progenitor cell differentiation. It regulates the balance between maintaining pluripotency and promoting differentiation by modulating the expression of key genes. For example, NuRD restricts the expression of pluripotency-associated genes, such as SOX2, to ensure that ES cells can progress to differentiated states when needed. Studies have shown that NuRD collaborates with the Polycomb repressive complex 2 (PRC2) to maintain differentiation genes in a state ready for rapid activation during developmental transitions [33].

By focusing on SOX2, a transcription factor essential for maintaining stem cell pluripotency and neuronal differentiation, NuRD's regulation of chromatin state directly influences SOX2 activity. NuRD acts to repress or activate specific enhancers and promoters associated with pluripotency and differentiation markers. The interaction between SOX2 and NuRD highlights the importance of chromatin remodeling in organizing complex developmental processes. If CHD1L binds to SOX2 in human developmental processes as seen in our studies, this would support a role for CHD1L in neurodevelopment.

EGR2 is not part of the NuRD complex but it plays a role in neuronal myelination and brain segmentation during development. If CHD1L binds to EGR2 in human development, this would be another indication of an important role in neurodevelopment.

Although our results are promising, some technical limitations must be acknowledged. For example, interactions detected in cellular or animal models should be interpreted with caution before being extrapolated to human development.

Furthermore, it would be interesting to examine the impact of CHD1L deletion or overexpression on neuronal differentiation, especially using advanced models such as brain organoids. Identifying protein interactions or pathways involving CHD1L could pave the way for innovative therapeutic interventions. For example, specifically targeting dysfunctional CHD1L interactions could offer solutions to modulate developmental abnormalities associated with ASD.

PERSPECTIVES

We plan to test the interaction of CHD1L with other transcription factors and regulators identified in pre-

liminary analyses, including HDAC2, OTX2, SMAD3, IGF2BP3, and RBBP4. HDAC2 is a histone deacetylase involved in chromatin regulation and transcriptional repression, while OTX2 plays a key role in neurodevelopment and maintenance of pluripotency. SMAD3 is a key mediator of TGF-β signaling, involved in transcriptional regulation during development and cell differentiation. In addition, IGF2BP3 is a post-transcriptional regulator of mRNAs, important for the stability and translation of target transcripts. Finally, RBBP4 is a component of chromatin remodeling complexes, involved in transcriptional regulation and gene repression [28]. Together, these proteins represent distinct layers of gene regulation - epigenetic, transcriptional, and post-transcriptional- offering a framework for understanding how CHD1L orchestrates transcriptional networks during brain development. Studying these interactions will help clarify CHD1L's contribution to neuronal differentiation and the molecular pathways that, when disrupted, may contribute to ASD. The extension of the scope of study will be possible through future co-immunoprecipitation experiments, which will explore other potential partner proteins of CHD1L identified by mass spectrometry and CUT&RUN experiments. To further investigate, co-immunoprecipitations with constructs without the macro domain will be performed. Because the C-terminal macro domain of CHD1L mediates PAR binding and exerts auto-inhibitory control over the ATPase domain, its removal would allow us to determine whether CHD1L interactions with pioneer transcription factors depend on this regulatory domain or instead occur through the ATPase independently.

The broader biological significance of our results is that they suggest a key role of CHD1L not only as a chromatin remodeler but as a partner of pioneer transcription factors during development. Our preliminary co-immunoprecipitation and Western blot data indicate that CHD1L interacts with pioneer transcription factors EGR2 and SOX2, both of which regulate gene accessibility during neuronal specification. These results suggest that CHD1L may influence activation of early neurodevelopmental gene programs - a process that, when altered, could underlie the macrocephaly and other phenotypic differences observed in some cases of ASD.

Ultimately, these results will move beyond establishing individual protein interactions to building a complete view of CHD1L's role in coordinating gene expression during neurodevelopment. By connecting molecular mechanisms to neurodevelopmental outcomes, this work may one day inform strategies for earlier diagnosis or intervention of ASD.

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