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The Temporal Politics of Placenta Epigenetics: Bodies, Environments and Time

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Abstract

This article builds on feminist scholarship on new biologies and the body to describe the temporal politics of epigenetic research related to the human placenta. Drawing on interviews with scientists and observations at conferences and in laboratories, we argue that epigenetic research simultaneously positions placenta tissue as a way back into maternal and fetal bodies following birth, as a lens onto children's future well-being, and as a bankable resource for ongoing research. Our findings reflect how developmental models of health have helped recast the placenta as an agential organ that is uniquely responsive to environments during pregnancy and capable of embodying biological evidence about the effects of in utero experiences after birth. We develop the concept of 'recursive embodiment' to describe how placenta epigenetics is reimagining relationships between bodies and environments across developmental, epigenetic, and generational time, and the impacts this has for experiences of pregnancy and responsibilities related to children's health.

Keywords

embodiment; epigenetics; maternal responsibility; new biologies; placenta; temporality

Introduction

The idea of bodies as shaped by their environments has gained increased attention in the life sciences, where the science of environmental epigenetics has become an exemplar of this approach. Environmental epigenetics focuses on how social forces including pollution, nutrition, stress, trauma and care can become molecularly embodied, alter gene expression without changing DNA sequence and influence the health of individuals, their offspring and future generations (Landecker and Panofsky, 2013). It is often described as how 'experience gets under the skin', providing a compelling biosocial narrative about the relationship between bodies and their environments (Aristizabal et al., 2019: 7).

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With the rise of epigenetic research, policy claims and tests, scholars of health, science and technology have reflected on how this science is shaping ontological and epistemic approaches to the body and embodiment. For example, Blackman and Venn (2010: 7) describe how shared ontologies across biology, social sciences and the humanities now 'emphasize the fact that social and natural phenomena are complex, processual, indeterminate, relational and constantly open to effects from contiguous processes' (Blackman, 2016). Others note how such 'new biologies' (Meloni et al., 2016) are distinctively 'intra-actional' (Yoshizawa, 2016), 'exposed' (Murphy, 2008), 'situated' (Niewöhner and Lock, 2018), 'entangled with' (Barad, 2003), 'embedded in' (Lock, 2015; Niewöhner, 2011) and 'constituted by' (Landecker, 2016) the historical present (Baedke, 2017; Meloni, 2018; Warin et al., 2016). While these analyses focus on antibiotic resistance, immunology, toxicology and the microbiome, here we are specifically interested in epigenetic research on the human placenta.

We ask: What do the logics and practices of placenta epigenetics signal about bodies, environments and time in the postgenomic era? And what are the impacts for experiences of pregnancy and responsibilities related to children's health? To answer these questions, this article draws on in-depth interviews with scientists and ethnographic observations of conferences and laboratories in the United States and Canada conducted from 2016 to 2021. We argue that epigenetic and Developmental Origins of Health and Disease (DOHaD) models of health have helped recast the human placenta as an agential organ that is uniquely responsive to environments during pregnancy and capable of embodying biological clues about the effects of in utero experiences after birth. This has produced placenta tissue as a valuable resource with the potential to provide insights into the lasting effects of pregnancy for 'both mom and baby' (Nelson, 2015: S12).

We show that scientists' accounts of the placenta suggest new understandings about the relationships between bodies, environments and time by simultaneously positioning placenta tissue as a way *back into* maternal and fetal bodies after birth, a lens onto children's *potential* well-being and a bankable resource for *future* research. These meanings matter because formulations of what the placenta is and does biologically are always already social (Haraway, 1991). The claims and practices of placenta epigenetics therefore reflect and construct bodies, environments and time in ways that influence responsibilities for health. Below, we review literature related to environmental epigenetics, temporality and the body, provide a brief history of shifting meanings of the placenta, describe our methods and discuss three findings that reflect the temporal dimensions of placenta epigenetics and their consequences.

Environmental Epigenetics, Temporality and the Body

Environmental epigenetics has recently become central in conversations about biosocial methods (Roberts and Sanz, 2018) and new biologies (Blackman, 2016) because of its potential to examine how infrastructures, inequalities and intergenerational experiences impact biology (Dow and Lamoreaux, 2020; Lappé et al., 2019; Meloni and Testa, 2014; Murphy, 2011). Despite this promise, many scholars argue that the molecular focus of epigenetics contributes to forms of 'epigenetic determinism' (Waggoner and Uller, 2015)

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and emphasizes individual behaviours over broader social conditions (Landecker, 2016; Lappé, 2016; Lock, 2015; Meloni, 2015; Richardson, 2015). These critiques introduce a tension in social studies of epigenetics between an emphasis on the contingency and relationality of bodies and their environments, and the molecular and individualistic implications of this science. Rather than adjudicate these debates, our analysis of placenta epigenetics illuminates how shifting models of health shape and are shaped by the temporal and 'epistemic cultures' of this science (Knorr Cetina, 1999: 1), and how bodies, environments and time are constructed within it.

In her ethnography of epigenetics in China, Lamoreux (2016) reminds us that epigenetic research and its social contexts are always co-constructed. She demonstrates how understandings of bodies as inseparable from their environments shape the social and biological meanings of epigenetics in that setting. This is in stark contrast to Western contexts, where the neoliberal emphasis on personal responsibility and bodily autonomy often reinforce individual and deterministic narratives of health. In the United States, these narratives remain central to biomedical research and risk communication, even as many scientists and physicians actively challenge them (Krieger, 1994, 2012; Shonkoff et al., 2021).

In the Special Issue of this journal on 'New Biologies', Meloni (2018) points out that bodies have in fact long been situated in their environments within Western science and medicine. What is unique in epigenetics, he argues, is its molecular claims and their extended time frames, which privilege biology and emphasize the potential transgenerational impacts of experience. Mansfield (2017) explicitly addresses these dimensions with her concept of 'epigenetic temporality', which focuses on how bodies are constituted by experiences in the present and past, primarily through the fetus. Her analysis suggests that 'perspectives on genomic and reproductive temporality help conceptualize environmental epigenetics as a dynamic relationship between plasticity and determinism' (2017: 355). Elsewhere, Valdez (2018) highlights how these relationships nevertheless redistribute reproductive responsibilities related to the 'environment' by focusing primarily on women's behaviours during pregnancy.

We build on these temporal dimensions of epigenetics through a focus on how the human placenta – a transitory organ uniquely coproduced by mother and fetus, and affected by social and biological milieu – is shaping epigenetic knowledge production and its consequences. This focus allows us to consider how embodiment is imagined and enacted through the growing use of placenta tissue within environmental epigenetics, and its effects on conceptualizations of health. Our efforts align with this Special Section's theme of 'biocircularities: a new theory that captures the way social, historical, and ecological changes are lived and experienced through the body and its times' (Poleykett and Jent, this issue). We contribute to this theory by considering how meanings and mobilizations of the placenta simultaneously rely on linear notions of time and reproduction, while also reflecting what we call 'recursive embodiment'.

The concept of recursive embodiment builds on Franklin's (2013) notion of recursion in her work on in vitro fertilization (IVF), conception modelling, and how reproduction is made

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through the merging of the social and biological. In the context of IVF and anthropology, she explains that 'the recursive relationship is a generative one' (p. 21). Her analysis shows how pluripotent cell lines are 'both tools and models: they are literally handles enabling a better grip on a practical problem. Yet they are also lenses, looking glasses, and representational amplifiers through which it becomes possible to see, apprehend and extract workable meanings from active biological cultures' (Franklin, 2013: 23). Here, we think about the placenta similarly: as a biocultural object that is made meaningful through the conceptualizations and practices of the scientists we follow and, in the process, shapes relationships between bodies, environments and time in meaningful ways.

We highlight how scientists' accounts of the placenta suggest its significance for health across three temporal dimensions: developmental time, epigenetic time and generational time. These dimensions point to the significance of critical windows of development (developmental time), the potential persistence of epigenetic changes leading to later disease (epigenetic time) and the embodied impacts of social history (generational time). They also create the conditions for understanding embodiment as recursive, because the body and its relationships to various environments are continually imagined in relation to what occurred in utero (see Lappé and Jeffries Hein, Forthcoming). In this way, the material instantiations of environments loop back on themselves (Franklin, 2013; Hacking, 1995), informing their embodied effects. The placenta is both a lens onto this process and the material through which it takes place. Before proceeding with our analysis, we discuss how relationships between bodies, environments and time have become differently parsed, punctuated and materially rendered through changing meanings of the placenta over time.

Changing Meanings of the Placenta

In their historical analysis, Martin and Holloway (2013) argue that the placenta has long been understood as 'a site of much exchange' across bodies (p. 303). Their work charts how the conceptual 'rise and fall of the placental barrier' has been shaped by changing 'norms regulating women's conduct during pregnancy' (Martin and Holloway 2013: 300–301). In contemporary Western biomedicine, the notion that the placenta served as a protective barrier is widely thought to have shifted in the 1970s due to medical tragedies among children whose mothers had been prescribed thalidomide for morning sickness and diethylstilbestrol to reduce miscarriage in the mid-20th century (Bell, 2009; Colls and Fannin, 2013). While views of the placenta as porous were already evident in medical literature (Martin and Holloway, 2013), these events elevated concerns surrounding women's exposures during pregnancy and brought new focus to their consequences for children's health. This was further influenced by the work of Barker and colleagues in the 1980s (Barker et al., 2010; Gluckman et al., 2008), whose studies documented cardiovascular effects in adult children whose mothers had suffered nutritional deprivation during World War II food rationing (Barker, 2007). In the 1990s, additional findings that alcohol and other drugs could also cross the placenta led to the 'endocrine disruptor hypothesis', which suggested the potential long-term developmental consequences of in utero exposures (Christensen and Casper, 2000; Kim and Scialli, 2011; Pasca and Penn, 2010).

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These events recast the placenta as a 'selective barrier' (Burton and Fowden, 2015: 6), and provided evidence of how the timing of prenatal exposures influences both fetal development *and* future health (Almond and Currie, 2011). This is reflected in the concept of 'critical' or 'sensitive windows of development,' which is now understood as one of the basic 'tenets' of developmental biology and morphology (Burggren and Mueller, 2015) and has been foundational to the rise of DOHaD research (Barker, 2007).

Anticipatory Care and Women's Responsibilities for Health

Feminist Science and Technology Studies (STS) scholars observe that DOHaD's primary focus on critical windows of development during pregnancy positions women as primarily responsible for the health of future generations. Scientists focus on these developmental periods because of the unique plasticity and programming of biological systems during this time (Richardson, 2017). As a result, pregnancy is often constructed as an ideal time for intervention, despite recognition that environments shape health throughout the life course. DOHaD research has therefore been critiqued for reinscribing familiar tropes of self-surveillance and anticipatory care work on expectant mothers within the broader history of medical and social surveillance of pregnant bodies (Lappé, 2016; Maher et al., 2010; Richardson et al., 2014; Waggoner, 2017). This has occurred around food and nutrition (Armstrong, 2003), vitamins (Al-Gailani, 2014), exercise (Dworkin and Wachs, 2004), pollutants, pesticides and plastics (MacKendrick, 2014; MacKendrick and Cairns, 2018), as well as social stressors that are structural, including racism (Davis, 2019; Kuzawa and Sweet, 2008), poverty (Link and Phelan, 1995) and the effects of natural disasters (Currie and Rossin-Slater, 2013). As a result, DOHaD research can reinforce the individualization of risk and women's responsibilities for children's health.

Yoshizawa (2016) and others (Fannin, 2014; Maher, 2002) argue that current placenta research has the potential to reshape such individualistic narratives as it 'enables us to recognize, account for, and attend to diffuse responsibilities for fetal–maternal outcomes that extend beyond mothers to the biosocial milieus of pregnancy' (p. 83). This is because, rather than seeing the 'mother, fetus, and placenta [as] essentially discrete', postgenomic research often situates them as constituting one another and shaped by their environments. This has the potential to shift responsibilities away from mothers alone and foster new ideas about 'what constitutes a "healthy pregnancy"' (p. 83). In pregnancy research more broadly, questions about immunity, chimerism, inheritance and genomic stability also increasingly challenge individualistic and deterministic narratives of health (see Blackman, 2010; Jablonka and Lamb, 2015; Lappé and Landecker 2015; Martin, 2010; Stotz, 2008). It is within this broader social and scientific context that placenta epigenetics complicates not only relationships between bodies and environments but linear notions of reproduction as well (Murphy, 2017).

Valuing the Afterbirth: From Biohazard to Biovalue

In addition to conceptual shifts surrounding the placenta's porosity and its impacts for bodily autonomy and responsibility noted above, there has been a significant rise in 'biovalue' associated with it (Haw, 2015; Waldby and Cooper, 2010). Today, the afterbirth has gained prominent attention as a 'natural resource' in commercial markets, therapeutic

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medicine and biomedicine (Annas, 1999: 1521; Benirschke, 1991). In therapeutic and regenerative medicine, placental derivatives and those from cord blood (Haw, 2015) are utilized in blood transfusions, transplants and for wound healing (Andrews and Nelkin, 1998; Brown and Kraft, 2006; Copeman, 2009; Santoro, 2011). Elsewhere, private umbilical cord blood and placenta banks, as well as pharmaceutical and cosmetic companies, capitalize on placenta stem cells for current use or as cryopreserved resources in anticipation of therapies and products (Franklin and Lock, 2003; Radin, 2017; Rajan, 2006; Thompson, 2005; Waldby, 2006).

Through these efforts, placenta tissue, cells and molecules gain a newfound social and medical status and 'mobility' as they are transformed and traverse bodies and 'multiple temporalities' (Colls and Fannin, 2013: 1093–1094; Hird, 2012). In this way, the placenta's biovalue (Waldby, 2002) is derived through the material extraction and transformation of its components for new uses. This process is highly gendered, as it is women's reproductive labour (Cooper and Waldby, 2014) that produces the very substrate that generates such value (Dickenson, 2007; Kent, 2008; Lamoreaux, 2018; Mitchell and Waldby, 2010).

These forms of biovalue now extend into biomedical research as well. While the placenta was long ignored in the biosciences and often labeled as waste following birth in medical settings (Annas, 1999; Martin and Holloway, 2013), in 2014 the National Institute for Child Health and Development (NICHD) launched a groundbreaking initiative called the Human Placenta Project (HPP). The HPP's goal is to study 'the least understood human organ but arguably one of the most important' by exploring 'human placental structure, development, and function in real time' (Guttmacher et al., 2015: 303). To date, the initiative has provided more than $50 million (USD) in funding, leading to the increased collection, storage and study of the placenta and growing recognition of its significance for health. These conditions, and the shifts described above, reinforced our focus on the temporal politics of placenta research within our broader study of environmental epigenetics.

Methods

Our multisited ethnography (Marcus, 1998) focused on epigenetic knowledge production related to children's health and its translation across laboratories, clinics and communities in the United States and Canada from 2016 to 2021. This article is based on the analysis of 40 in-depth interviews conducted with epigenetic scientists from disciplines including pediatrics, psychology, psychiatry, molecular biology, epidemiology, genetics and biochemistry, and approximately 200 hours of laboratory and conference observations that took place as part of our larger study. The labs we observed and scientists we interviewed were selected because of their expertise in behavioural, social or environmental epigenetics related to children's health.

Central to our sites was the Epigenetics Lab, a Canadian University-based laboratory and interdisciplinary research group that has become increasingly central to the epigenetics of children's health.[1] The lab conducts studies and collaborates with hundreds of researchers

[1]·The Epigenetics Lab is a pseudonym.

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internationally. Our observations there included inperson and virtual attendance at lab meetings, in-depth interviews with scientists and observation of research activities, and correspondence with the Principal Investigator (PI) and lab members about publications and grants. Our ethnography focused on the epistemic culture of the lab, researchers' views on the ethics and social impacts of their work, how disciplinary approaches shaped their studies and the circulation of biological samples over time and across locations. This lab also provided a case study of epigenetic knowledge production by suggesting how conceptualizations of the placenta shape and are shaped by scientific practice.[2]

While many samples are lively in epigenetic research, the placenta drew our attention for empirical and personal reasons. For example, while pregnant and observing another lab in the United States from 2014 to 2018, the first author watched researchers painstakingly dissect tiny frozen placentas from a cohort of mouse dams and process the tissue to identify epigenetic modifications. Their goal was to understand how dams' stressful experiences during pregnancy mapped onto pups' future behaviour. In that lab, where nearly all members were women, they described the underappreciated complexity of the placenta and the unique impacts their research in mice could have on human maternal and child health (see Lappé, 2018).

These moments and the presence of the placenta during our recent fieldwork brought questions about its biosocial meanings into view for us as feminist scholars and mothers. Our centring of the placenta as an important scientific and cultural object therefore not only provides a lens onto epigenetics but situates women's reproductive labour as central to the development and temporal politics of new biologies. Below, we describe three temporal dimensions of placenta epigenetics and their impacts on the relationships between bodies, environments and time.

Findings

The Adaptable, Plastic and Communicative Placenta

In this section, we describe how scientists characterize the placenta as *adaptable, plastic and communicative*, and therefore central in shaping fetal development in lasting ways. Scientists' conceptualizations of the placenta as adaptable, rather than a mere conduit, mirror postgenomic notions of genomes as reactive and responsive (Gilbert, 2003; Keller, 2014). Their accounts also reflect the prominence of what we call 'developmental time' in placenta epigenetics. This temporal dimension aligns with DOHaD models of health by emphasizing how exposures and experiences during critical windows of in utero development can shape future health.

In the Epigenetics Lab and throughout our interviews, researchers characterized the placenta as capable of adapting and responding to the maternal body and women's experiences of the world, as well as communicating critical signals between the fetus and mother

[2]Case studies have been generative for STS studies of bodies and embodiment (Law, 2017). Our analysis builds on this, using grounded theory to analyse our data within the broader 'situation' (Clarke et al., 2017) of contemporary postgenomics and the environmental politics of reproduction (Lappé et al., 2019).

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during pregnancy. A psychiatrist and maternal and child health expert described this while discussing her research on women's mental health during pregnancy. She explained:

> The placenta does all these functions, but it can *adapt a lot and try to compensate*. When it's having problems doing one function, it may be able to alter its functions to try to deal with that. That's where I think looking at epigenetics in the placenta is really exciting because it is such an *adaptable* organ.
>
> (Participant 7, April 4, 2017, emphasis added)

She went on to describe the unique role the placenta plays in fetal development and the impacts if those functions are altered:

> Placentas are really interesting … it's a transitional organ. It's only there for so long, but it plays really important roles throughout pregnancy. It acts almost like a number of other organs during this short period of time. It acts like a liver, immune system, brain and neuroendocrine system. It has all these different functions, so you can imagine if you start altering the way it performs any of those functions, that could be what's leading to changes in the development of the child, because it has this remarkable plasticity to it.
>
> (Participant 7, April 4, 2017)

This quote suggests the important role that the placenta plays in shaping future health and harkens back to two tenets of DOHaD. The first is the focus on pregnancy as a 'critical window', and the second is how epigenetic modifications can occur because of the unique plasticity of developing systems during this time. These two logics are foundational to how 'developmental time' emerged in researchers' accounts and suggest how questions of epigenetic plasticity and stability remain tethered to early life (see Lappé and Jeffries Hein, Forthcoming).

A clinical research psychologist described connections between developmental plasticity, the timing of experiences, and their lasting impacts when discussing her research on how microbial changes during pregnancy can influence children's brain development and behaviour after birth. She said:

> I think in terms of a plasticity period in the human … [that] seems to be prenatal to four years of age. We know from human studies that even though we thought the in-utero environment was sterile, it seems it is not. Maternal microbes have been detected in the placenta … and early features of the parent-child relationship tend to set up the microbiome.
>
> (Participant 10, May 18, 2017)

The idea of the in utero environment as open to maternal experiences, and the placenta as adaptable and plastic, provided the conditions for researchers to imagine the placenta as *communicative* as well.

This was a key theme during the inaugural *Placenta Symposium* at Johns Hopkins University in 2018 where experts across numerous biomedical fields described the importance of developmental models in their descriptions of how the placenta influences

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children's health. The keynote presenter described his research on placenta adaptability and communication in the context of the 2016 Zika epidemic. Motivated by the neurodevelopmental effects of the virus, his lab began focusing on 'multinucleated syncytiotrophoblast cells'. He described how these cells are fetal in origin but release 'vesicles', including exosomes, into maternal circulation, suggesting a mechanism through which the placenta *communicates* with 'the world' (Keynote Presenter, May 4, 2018). He explained their importance for maternal–fetal–placenta interaction, stating:

> The communication of the fetus to the world occurs right there in that interface … The multinucleated syncytiotrophoblast – these cells are *the forefront of the fetus for the environment.* Everything else, the mother and [beyond] the mother, *everything else is the environment for the fetus*. So any interactions or cares we need to think about [regarding] what happens during pregnancy – exposures, influences – everything happens right here between the fetus and the environment.
>
> (Keynote Presenter, May 4, 2018, emphasis added)

These 'magical vesicles', as another presenter described them, provided researchers an opportunity to elucidate 'how these cells communicate with maternal tissues, and how they may also communicate with fetal tissues' (Conference Presenter 4, May 4, 2018). For the keynote presenter, illustrating how the placenta could mediate the harmful effects of Zika also provided evidence of the specific mechanisms involved in how the environment gets 'under the skin' (see Tannetta et al., 2017). These accounts suggest how researchers' conceptualizations of the placenta as *adaptive, plastic* and *communicative* produced a sense of bodies as uniquely affected by their environments during specific periods of development. This temporal focus also structured how scientists thought about health interventions, as we describe below.

Holding On: Placental Regulation, Biomarkers and the Embedding of Experience

In this section, we discuss how our interlocutors' visions of the placenta as *responsive* and *regulatory* during pregnancy positioned the afterbirth as a valuable resource in shaping potential interventions. Here, scientists characterized placenta samples as providing a 'retrospective window into the womb' because they can embody epigenetic modifications as a result of in utero experiences (Participant 35, July 16, 2019). This positions placenta epigenetics as an opportunity for researchers to go 'back in time' and identify potentially predictive biomarkers of children's future health (see Pinel et al., 2019). Scientists' accounts therefore point to the importance of 'epigenetic time' in placenta research. This temporal dimension captures how 'the environment' is increasingly thought to matter through epigenetic logics, despite questions about the persistence and impacts of modifications over time. This phenomenon dovetails with broader concerns about the molecularization of the environment in epigenetic research (Lock, 2015) and the anticipation of health risks that orients much of biomedicine (Adams et al., 2009).

Reflecting on the placenta's role in understanding future health, a prominent psychiatrist in the field explained,

> I know that I'm not looking at the fetus proper. I know that the epigenetic marks I'm seeing in the placenta are not necessarily what's going on in the child … [But]

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> the placenta being so functional, those effects might be really important at least during those nine months and potentially long-term, because they may be leading to physiologic programming in that developing fetus that *holds on* and is sort of set for a lifetime
>
> (Participant 7, April 4, 2017)

Understanding the placenta's long-term impacts was also evident in a presentation by a maternal–fetal physician. Her talk focused on the placenta's role in fetal brain development. She explained,

> [The placenta] serves a lot of functions where it's *not purely a conduit*. I know sometimes it is considered just a conduit from which maternal environment is transmitted … but it plays a key role in the regulation of development and in regulating all the answers that mom is giving to baby in regard to inflammation exposures, infection exposures, [and] toxic exposures in pregnancy.
>
> (Conference Presenter 2, May 4, 2018)

As she discussed the placenta's regulatory functions, she did so in relation to the social and medical costs of preterm births. For her, being able to predict which pregnancies were most at-risk and the ideal 'windows of opportunity' for intervention, required ascertaining *how and when* exposures mattered so she could identify 'which baby is to go on to develop problems' (Conference Presenter 2, May 4, 2018). Another researcher studying autism spectrum disorders captured how this anticipatory logic related specifically to epigenetic findings, stating:

> It's possible that epigenetic marks can be biomarkers of exposure … [and] that might be useful whether or not they're mechanistically relevant, but simply as *predictors*. And another utility is … that epigenetic marks … may be great biomarkers of outcome or prognosis.
>
> (Conference Presenter 3, May 4, 2018)

Identifying at-risk pregnancies and intervening early was a motivation for many of our interlocutors, including a developmental psychologist who focused on identifying 'biomarkers of particular environmental exposures … [because they] could be useful for preventing future cases' (Participant 5, March 10, 2017). She described the relevance of her research on maternal stress during pregnancy for policy, explaining:

> When you're looking at all of those stressors and you're finding effects on the brain, on these physiology systems, and at the level of the gene – it becomes a much more powerful story that, wow, these stressors are *getting under the skin, becoming biologically embedded*, and there's like a *biological residue as a result of these exposures that really could have life-long consequences that stick with the child*. And that may be a more powerful story for policy makers to latch on to and then, hopefully, in turn, allow them to support those populations.
>
> (Participant 5, March 10, 2017)

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Her hope that epigenetic findings could shape policy connects the logics of developmental *and* epigenetic time by emphasizing the importance of molecular changes during specific developmental periods as evidence for interventions (see Lappé and Landecker, 2015).

A molecular epidemiologist reiterated this view in his description of the importance of in utero development, stating:

> what the baby elicits from the parents already begins … It's such an optimal time for many reasons to get in there and at the beginning of this really complicated bidirectional process, *try to get everyone on the right track*.
>
> (Participant 7, July 21, 2017, emphasis added)

In the examples above, the search for epigenetic biomarkers reflects how scientists saw the placenta as an opportunity to anticipate the future and a resource informing early interventions. As a pediatrician noted, 'you can't change genotype, but you *can change gene expression*. [And that] opens up all the possibilities for modification, environmental effects, and potentially treatment' (Participant 8, May 12, 2017).

Across our data, these discussions were notable because they suggested an understanding of the placenta as 'holding onto' in utero experiences after birth and molecular knowledge as influential in anticipating the future. With this possibility in mind, scientists' explicitly tied placenta epigenetics to the promise of temporally specific interventions in ways that continued to situate pregnant bodies as avenues for children's health or harm. This occurred despite researchers' recognition that bodies are permeable and impressionable throughout the life course, as we describe below.

Constructing Epistemic Claims in Placenta Epigenetics

In this final section, we describe how researchers discussed longitudinal birth cohort studies and ongoing data collection as necessary tools for effectively interpreting epigenetic changes in the placenta. These approaches emerged as key modes of *epistemically stabilizing* placenta epigenetics as biologically meaningful for later health, reflecting what we call 'generational time'. This temporal dimension reflects how the importance of early life remains contingent on emergent understandings of how and when experiences shape bodies over the life course and intergenerationally. Scientists' longitudinal research therefore connects the placenta not only to the mother, fetus and their environments during pregnancy but to the histories and social contexts that shape bodies and lives before and after birth.[3] This complicates interventions that solely focus on pregnancy by recognizing embodiment – and knowledge practices related to it – as recursive and ever-changing processes.

Despite their predominant focus on pregnancy, scientists we interviewed and observed explained that the ongoing collection of data through longitudinal and birth cohort studies was necessary to anchor placenta findings as empirically meaningful for children's health for three related reasons. First, questions about the persistence and interpretation of epigenetic marks remain unsettled (Aristizabal et al., 2019). A developmental psychologist

[3]Epigenetic studies also focus on paternal effects and children's health, though this was much less prominent across our sites (see Almeling, 2020).

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studying the effects of maternal mood during pregnancy and emotional regulation in newborns explained,

> We really don't know the stability of methylation, even in one or two key genes longitudinally and I think, in part, that's because this is a newer area. So, in order to test those questions we need to start from scratch … obviously, if you're starting with the placenta, you have to stop with the placenta. You're not gonna be able to look at that longitudinally. [So] we are collecting buccal cells at the newborn period and at five months, and we want to do it at 18 months [so we can ask] 'What is the stability of methylation in early childhood?'.
>
> (Participant 5, March 10, 2017)

Second, scientists saw these studies as ideal for establishing biological pathways related to in utero exposures because they constructed a 'postnatal package' of urine, blood, saliva, breast milk, psychosocial and demographic data and other environmental information, which was important because 'different specimens tell you different information' (Participant 8, May 12, 2017). Connecting longitudinal data collection to the discussion of biomarkers above, a pediatrician explained,

> There may be different information contained in epigenetic effects in buccal cells versus blood, versus whatever else you wanna look at. Another possibility is that … [what you find in the placenta is] an epigenetic *footprint*, it's telling you that something went on here that relates to epigenetics, and now we gotta figure out what it is. And from that perspective, you might say, 'Well if I look at different tissues in the same patients, and I see footprints in these different tissues, then that strengthens the argument that there are epigenetic phenomena going on here that we can then pursue.' So that's one direction that we're going, and we're trying as much as possible to collect … multiple specimens on the same kids. Placenta, buccal cell, blood … and I think that's just gonna be an ongoing line of research until we figure some of this stuff out.
>
> (Participant 8, May 12, 2017)

A prominent epigeneticist described a similar approach, explaining that his lab was expanding their longitudinal birth cohort study by collecting biospecimens from the same children at ages one and five to provide a potential 'match' between epigenetic signatures found in placenta and those in other tissues collected at other points in the lifespan. He said,

> Obviously it would be documented, seeing signatures in cord blood or in the placenta, but now that we have *the match*, we can actually [ask] … [Are these] the same signatures from the same samples? Is [the exposure] a bigger impact on the placenta? Bigger impact on [umbilical] cord? … we have been over the years trying to compare two, three different tissues from the same person [to answer this question].
>
> (Participant 35, July 16, 2019)

These comparisons were important because they allowed researchers to understand whether epigenetic modifications occur across different tissue types, in relation to the same or distinct environmental exposures, and their stability and impacts over time. Addressing these

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questions had the potential to shape future research and interventions: If changes in the placenta 'match' with later biospecimens and phenotypic outcomes, then the question of how early life experiences shape health outcomes becomes more pressing. If they do not, then researchers must more fully account for the various environments that shape bodies across lifetimes.

Finally, scientists studying placenta epigenetics also collected additional biological samples for practical purposes, including waiting for databases to become more robust and for funding to support further research. Collecting longitudinal data was therefore a routine but important feature in their efforts to make claims about the relationships between bodies, environments and health over time. An epidemiologist enthusiastically described her study design, stating:

> The whole basis of the research happening [here] is cohort studies that follow kids from pregnancy out. Our oldest kids are now 19 years old, so we have information about their pregnancy, what they're environment – big E-environment – was like *in utero*, and now what this kid looks like when they're 19. It's amazing.
>
> (Participant 18, August 29, 2017)

In her lab, the ability to collect and analyse these data over time was central for their work on maternal stress and child development, where they analysed epigenetic findings alongside telomeres as a 'good proxy for an objective measure of adversity'. She explained, a lot of what we do, truthfully, is collect samples and bank them. That way, when a new marker comes online, we have the samples ready to go. If you have to build a study each time you want to study something, it's incredibly inefficient and wildly expensive. (Participant 18, August 29, 2017)

The psychologist quoted above reiterated the importance of this approach while acknowledging the critical role of funding in shaping its impacts:

> I have no funding to look at methylation, longitudinally, across those time periods. It's so expensive. I'm just hoping it's less expensive to collect those samples and then I'm hoping that they keep for a few years, so I can actually look at the methylation eventually, hopefully get a grant to look at that.
>
> (Participant 5, March 10, 2017)

These accounts suggest the importance of not only generational time in assessing the importance of the placenta but the impacts of broader scientific infrastructures in shaping the outcomes of epigenetic research. Here, questions about the origins, stability and effects of epigenetic changes are negotiated through ongoing research practices that are themselves shaped by shifting knowledge about the relationships between bodies, environments and time.

Conclusion

The sections above illustrate how scientists working across multiple disciplines see the placenta as an agential and relational organ that is uniquely responsive, regulatory and capable of communicating across bodies and environments in influential ways during

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pregnancy. In their accounts, the afterbirth is imbued with biovalue (Waldby, 2002) because of its ability to embody the effects of in utero experiences after birth and inform interventions. Further, scientists' research is accomplished through practices that are themselves temporally paced: Longitudinal birth cohorts draw on comparisons across data and over time to stabilize epistemic claims about the epigenetic effects of early life. As such, conceptualizing, collecting, storing and studying placenta tissue alongside other data has become central to the production of biomedical knowledge about the body.

For researchers, epigenetic and DOHaD models of health support new understandings of *how and when* relationships between bodies and environments matter. We have shown that their conceptualizations of the placenta also suggest how developmental time, epigenetic time and generational time intertwine to inform what this unique organ *is and does*, as well as its bearing on the future. These findings reflect how the placenta has become both prophetic and a cypher, providing clues about the future while embodying the past.

The logics and practices of placenta epigenetics thus evoke a sense of embodiment as recursive. By this, we mean that researchers' empirical investigations use the placenta to root questions about health and development in pregnancy, even as they actively investigate how environments influence bodies over time. In this way, epigenetic logics loop back on themselves: They allow scientists to envision human biology as uniquely shaped by the maternal–fetal environment, while also recognizing embodiment as a contingent process that unfolds over and across lifetimes. Placenta epigenetics therefore relies on biomedicine's tendency to molecularize health and anticipate future risks, while also suggesting ways of thinking otherwise. It's practices allow for a return to the womb, but one that changes ideas about embodiment by producing a temporal politics that extends *from the womb to the world*.

Through their constructions of the placenta, the scientists we study consider bodies, environments and time as intimately shaping one another in ways that matter both biologically and socially. They connect their research to the need for policies supporting racial and gender equity, access to nutrition and medical care, clean air and water, and awareness of the intergenerational impacts of adversity (see Champagne, 2010). In doing so, they move beyond biological determinism (Lock, 2015; Waggoner and Uller, 2015) and complicate individualistic notions of health, while nevertheless focusing on how experiences during pregnancy may shape the future.

This means that modes of biomedical surveillance focused exclusively on early life and gendered responsibilities for care are insufficient to address the complex temporal dimensions of embodiment. Body and embodiment scholars of course know this, but the researchers we study recognize it as well. Here, we have shown how placenta epigenetics connects the present to the future and past in ways that extend across life times, bodies and environments. Our findings therefore point to collective responsibilities for health, and the need to recognize how social and structural environments shape bodies long before *and* after birth.

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