**16 AUG 2022**

**Personhood with Human Potentialities: The Biomedical Framework for Pre-birth Attribution of Personhood is Incremental and Includes Both Punctualist and Gradualist Features**

**Claude L. Hughes**

Department of Obstetrics and Gynecology

Duke University Medical Center and

Therapeutic Science and Strategy Unit, IQVIA

Durham, North Carolina, 27710 USA

[clhughes@duke.edu](mailto:clhughes@duke.edu)

and

**Gavin C. Hughes**

Departments of Philosophy and Biology

University of North Carolina at Chapel Hill

Chapel Hill, North Carolina, 27599 USA

[gavinch@email.unc.edu](mailto:gavinch@email.unc.edu)

Conflict of Interest Statement: Both authors (C.L.H. and G.C.H.) hereby state that neither has any financial or other material, professional, or scholarly relationships that involve the area under discussion in this essay including conflicts such as honoraria, payments, stock holdings, and other relationships as identified in the 2002 statement of the Council of Editors of Scientific Journals and of the Center for Science in The Public Interest.

**Abstract**

Discrete events and processes influence development of individual humans. Attribution of personhood to any individual human being cannot be disconnected from the underlying biological events and processes of early human development. Nonetheless, the philosophical, sociological and legal components that are integral to the meaning of the term as commonly used cannot be deduced from biology alone. The challenge for biomedical scientists to inform discussion in this arena then rests on profiling the key biological events and processes that must be assessed when considering how one might objectively reason about the task of superimposing the concept of personhood onto the developing biological entity of a potential human being. Endogenous genetic and epigenetic events and exogenous developmental *milieu* processes diversify developmental trajectories of potential individual humans prior to livebirth. First, fertilization and epigenetic resetting of each individual’s organismic clock to time zero (t=0) at the gastrulation/primitive streak stage (day 15 of embryogenesis), are two discrete discreet biological events that impact a potential individual human’s attributes. Second, those two discrete discreet biological events are immersed in the continuous developmental process spanning pre-fertilization and gestation, further driving individualization of diverse attributes of each future human before the third discrete and blatant biological event of parturition and livebirth. Exposures of the gravida to multiple diverse exogenous exposures means that morphogenesis and physiogenesis of every embryo/fetus has individualized attributes for its future human lifespan. Our proposed framework based on the biological facts spanning pre-fertilization and prenatal developmental discrete events and processes, implies that personhood should be incrementally attributed and societal protections should be graduated and applied progressively across the pre-birth timespan.

Keywords: personhood, epigenetics, biological organismic clock, physiogenesis, potential human, future human

**Background**

Across human history, by introducing an individual human into society, the discrete, blatant biological event of parturition and livebirth definitively marked the attribution of personhood for that individual human. In recent decades, the concept of personhood has been elaborated and debated in multiple contexts including legal, theological, secular, scientific and philosophical. Notably, discourses relating to the time at which personhood can be attributed to a developing potential human have oftentimes reached divergent conclusions (Kerckhove and Waller 1998; White 2013). In the book *Personhood Revisited* (Jones 2013, page 150), Professor Howard W. Jones, Jr., one of the founding parents of human in vitro fertilization medical practice in the United States, listed the definition of personhood to be "A status acquired during human embryonic development that confers protection by society." It is our current contention that both new and well-established scientific insights can provide a framework by which such considerations regarding development of human individuality and attribution of personhood might be better made. In the scientific realm, advances in reproductive technologies across recent decades necessitated carefully considered ethical and scientific assessments and implementation of guidelines for medical and scientific practices (Ethics Advisory Board 1979; Warnock 1984). As scientific knowledge has accumulated about human birth, gestation, implantation, fertilization, gametes, and genetics, the beginning of human personhood has been defined by various endpoints related to each of these biological processes (Warnock 1984; Jones 2013). Associated with each such biological endpoint, ethical, legal, theological and secular social interpretations have been superimposed.

In chapter 7 entitled *“Personhood”* (Jones 2013, pages 85-104), Jones summarizes much of the history of the concept of personhood including philosophical (ethical reasoning), theological (religious beliefs), secular (includes scientific fact-based interpretations as well as other non-theological lay public opinions), and legal (laws, enforcement and court decisions) considerations regarding the concept of personhood. He makes a pragmatic comment on page 104, "As said previously, it is necessary from a practical point of view to select one of the events previously described as THE event that indicates personhood…Viability, the ability to survive without being attached to the mother is surely THE major biological milestone indicating personhood." While we agree with his point that presumptive viability is A robust prenatal indicator of personhood, we do not agree that a single developmental stage or event may or should be pragmatically selected to fully bestow the status of personhood before birth. Our argument is that the endogenous and exogenous biological, fact-based scientific evidence makes it clear that application of the concept of personhood must be accrued incrementally over the course of early development. It is frankly irrational to conclude that personhood is completely absent at one moment and completely present at the next, via some singular instantaneous transitional event. From this fact-based and reasoning-based (scientific and philosophical) perspective, we support the contention that incremental accrual of attributes is the most coherent framework for personhood that encompasses prenatal individualization of humans by serial and concurrently acting endogenous and exogenous developmental factors. One non-biological definition of personhood is the quality or condition of being an individual person. That definition on the surface just implies that someone exists, not that they are a unique person with many diverse traits. However, as we aim to profile the biomedical bases for the concept of personhood, we are explicitly stating that a human does not have personhood without also possessing highly individualized, complex mix of human traits quite akin to the related notion of "personal identity." Persons are unique living individual humans.

As profiled by Greasley (p. 7; 2017), there are long-standing philosophical debates about when persons begin to exist, and arguments broadly fall into either punctualist or gradualist theses. Biologically, from the earliest stages of initiation of a potential human being, accrual of progressively more advanced attributes are most rationally interpreted as being a mixture of both notable events that are limited in time but feature drastic developmental changes, but also a spectrum of processes which cannot be simplistically divided into individual events but are essential to the development of patterns of biological functions that lead to development of individual potential humans. In other words, biologically there are events and processes and both of these punctualistic and gradualistic elements are essential temporally-dependent components of prenatal human development.

If philosophical considerations of personhood prior to livebirth are to be rooted in observable scientific facts, then some suppositions and interpretations may necessarily change as new scientific data are gathered. For example, as regards the philosophical tractability of debate about attribution of personhood, Dworkin (p. 10, 1993) has stated “…there is no biological fact waiting to be discovered or crushing moral analogy waiting to be invented that can dispose of the matter.” To the contrary, there are in fact recent basic laboratory research discoveries, two of which may have a profound impact on the attribution of personhood to potential humans.

First, in recent research, Palmerola et al. (2022) have demonstrated that a high rate of biological attrition of preimplantation embryos in IVF is due to failure of DNA replication. It is reasonable to hypothesize that this is not merely attributable to IVF culture conditions, but rather the same process plausibly occurs in normal human reproduction. If that reasonable expectation is true, then a punctualist view that personhood begins at fertilization is severely compromised because that would mean perhaps 1/3 to ½ of all developing human embryos who might be designated as persons will undergo spontaneous death even before implantation.

Second, Kerepesi et al. (2021) have demonstrated that individual mammalian embryos appear to have an epigenetic clock that resets to a time zero at the primitive streak stage. This is a new biological fact that has been recently discovered and arguably is a punctualistic event that should now be considered and added to the array of events and processes that are recognized to be part of early normal human development several days after implantation. Ongoing cellular and molecular research are likely to demonstrate other key events and processes in morphogenesis and physiogenesis in relevant animal models and humans.

In Table 1, we summarize correlations of biological and medical processes and events with bioethical attributions of personhood from both punctualist and gradualist perspectives. It is noteworthy that multiple important biological events and processes that occur early in human reproduction and development are highly stochastic and seem to generally be of limited interest in discussions of acquisition of personhood. For example, potential effects of germline mutagens on oocytes or spermatozoa, factors affecting gametogenesis, survivorship of preimplantation embryos, accounting for losses of potential or actual early pregnancies due to biochemical pregnancies (transient positive hCG tests, perhaps 10-30%), spontaneous or inevitable abortions (some 15-25%) (Dugas and Slane 2021) and ectopic pregnancies (about 2%) all raise objective quantitative challenges to a punctualist attribution of full personhood to zygotes or embryos around the events of fertilization, implantation and pregnancies during the early post-implantation interval. Later in pregnancy in the first and second trimesters, several of the potential obstetrical observations that may be used to document potential landmarks of progressive fetal *in utero* development require use of ultrasonic imaging which is routinely available in many locations but is not readily available in many others. Such differences raise the specter that assignment of personhood (or not) would depend upon the geographic distribution of healthcare technology. This notion that attribution of personhood to a fetus *in utero* might primarily depend upon the exogenous factor of access of the gravida to medical technology is relevant to public policy and legal status, but will not be further addressed in this paper. Similarly, in many global regions, extremely preterm neonates will effectively have no plausible chance to survive due to unavailability of intensive care nursery services. Thus in this latter case, is there a coherent rationale to attribute personhood to every fetus at 22-24 weeks EGA even though many who are liveborn at that age will promptly die due to the stochastic element of the gravida’s geography?

Additionally, over the entire embryonic and fetal intervals, endogenous maternal and exogenous exposures influence development of diverse characteristics, many with sustained effects well into postnatal life, even lifelong.

**Prenatal Determinative Transformational Events**

Many genetic, epigenetic, and developmental *milieu* effects from pre-fertilization through livebirth determine each individual's unique combination of attributes upon societal entry. For our purposes in this paper, we define two terms as follows:

1. Potential human: The stages of human development spanning initial interactions of one female and one male gamete such as the spermatozoa binding to the zona pelucida up to gastrulation, formation of the primitive streak, resetting of the epigenetic clock, progression through gestation and parturition.
2. Physiogenesis: The partner concept to morphogenesis; meaning the acquisition of molecular, cellular, tissue, organ, system and organismic level functions to allow future individual life. Morphogenesis and physiogenesis determine future potentialities for individual persons.

We contend that there are three discrete events and multiple continual/continuous processes that determine the individual attributes of a potential human. We present our framework that during prenatal development, a future human becomes an individual by the overlaying of a complex individualization process onto the three known discrete determinative events, namely fertilization, the novel epigenetic time reset and livebirth. The developmental individualization process is the product of a spectrum of factors, both endogenous and exogenous, that incrementally influences acquisition of multiple attributes and thus incremental accrual of personhood prior to and then fully upon livebirth.

Although we are arguing for the importance of a recently discovered biological event, the resetting of the epigenetic clock (approximately Day 15 of embryonic life for human embryos; Kerepesi et al. 2021), we also argue that it is insufficient to solely determine personhood because no single developmental event adequately encompasses the entire process of prenatal developmental individualization of humans. Across the course of prenatal development, becoming an individual depends upon multiple genetic, epigenetic and other morphogenic/physiogenic organizational processes such that individualization is a summation of all of the developmental determinants that cause or modify the acquisition of biologically definable metabolic, morphologic, behavioral, and reproductive attributes.

**The Two Discrete Discreet Events of Fertilization and Epigenetic Time Reset**

1. Fertilization and Parental Genetics

It is widely understood that the genetic attributes of each individual are robustly dependent upon parental genomes and that individual diversity within a population is profoundly dependent upon random assortment of alleles and meiotic recombination that had occurred in parental gametogenesis. The key biological consequence of these processes in gametogenesis is diversification of the genomes of progeny. Each array of inherited genes provides combinations that may mimic or diverge from the phenotypic traits of the parents, because most human traits are a product of a non-Mendelian complex interaction of multiple genes. (de Magalhães and Wang 2019)

2. The Epigenetic Organismic Clock Reset to Time Zero (t=0)

The broad context of epigenetics in human embryonic development is that there is a general “wiping the slate clean” but also a rather modest degree of retention of some parental epigenetic marks. This predominant but incomplete erasure of epigenetic marks has attracted great research interest as well as debate about how important or unimportant epigenetic inheritance may be for any individual (Thompson and Einstein 2010; Heard and Martienssen 2014; Boskovic and Rando 2018; Tuscher and Day 2019; Osumi and Tatehana 2021; Soubry et al. 2021).

As an outgrowth of epigenetics research in the embryo, Kerepesi et al. (2021) have studied the temporality of epigenetic events. Their recent publication makes the case that they have characterized the time and event that is the beginning of aging for each individual mammal. These investigators used machine learning to develop a new multi-tissue epigenetic clock. They used this new clock and others to assess aging in prenatal mammalian development. In the mouse model, these investigators reported a rejuvenation period during early embryogenesis and the onset of the beginning of aging after this rejuvenation event. Their observed epigenetic age minimum in the mouse was at E6.5/E7.5 which corresponds to gastrulation, formation of the primitive streak and the three germ layers. This embryonic developmental stage in human embryos occurs on approximately embryonic day 15. Kerepeski et al. (2021) go on to state the following:

Our study suggests that the germ line ages but is rejuvenated in the offspring at some point during early embryogenesis. This rejuvenation occurs during early post-implantation stages corresponding to gastrulation when the offspring reaches its minimal biological age. We propose that this minimum, the ground zero, marks the beginning of aging of an organism… The data indicate that ground zero lies between E4.5 and E10.5 in mice, most probably at E6.5/E7.5. This period corresponds to the germ-layer specification (gastrulation) accompanied by the exit from pluripotency… Our current work now pinpoints the beginning of aging to ground zero… Overall, this work identifies a natural rejuvenation event during early life and suggests that organismal aging begins during embryogenesis, approximately at the time of gastrulation.

**Diverse Exogenous Factors Influence Pre-Fertilization, Embryonic and Fetal Attributes of Individual Humans**

Attribution of personhood to a developing human at or before birth is not an end unto itself. For an obstetrician or pediatrician, that initiation of a new individual human life is only the beginning of what is a life trajectory that has hopefully been developed as a consequence of favorable pre-birth factors.

From a biomedical point of view, characterizing the pre-birth developmental course of human beings as a parsing of observable facts into two presumptively distinct categories of events versus processes is admittedly somewhat simplistic, but does serve as a useful construct in research, organization and documentation of scientific knowledge and in medical practice. We shall use this bipartite approach to a) review the various events and processes that are known to be relevant to pre-birth development of humans and then to b) argue that to the extent that biomedical facts underlie the progressive acquisition of attributes that are relevant to life *per se*, health, longevity and functional status (potential quality of life parameters), incremental rather than absolutist attribution of personhood is more parsimonious with biological facts.

The range of potential cell types during human *in utero* development that might be affected by exogenous factors are not yet fully elucidated, but there is a global effort underway to do precisely that; namely, to create a comprehensive reference map of cells during development (Haniffa et al. 2021). Even though the precise identity of cellular targets during development are not fully known, stochastic exogenous environmental and intrauterine *milieu* factors are known to impact the developmental trajectory of humans (Thompson and Einstein 2010; Skogen and Overland 2012). The conceptual challenge in understanding prenatal development with or without exogenous perturbations is to formalize how emergent properties arise via dynamic interactions at both higher and lower levels of biological organization. Such theoretical and analytical network modeling research is occurring (Cavigelli et al. 2021), with, for example, more than 100 studies currently underway under the auspices of the National Institutes of Health MultiScale Modeling Consortium (<https://www.nibib.nih.gov/research-funding/interagency-modeling-and-analysis-group-imag>).

Disruptions of structural and functional development occur and there is a long history of scientific study of such variations from the normative patterns. Specifically, the scientific discipline of teratology was historically rooted in morphogenesis and disorders thereof, and we assert that the later broader term of developmental toxicology had helped add dynamic integrated elements that we herein call “physiogenesis” as its *sine qua nom*, as it focuses on how exposures to various physical, chemical, biological and social factors may adversely affect the health and functional well-being of an individual human.

While teratology/developmental toxicology research primarily seeks to understand adverse effects of the many exposures that inevitably occur during development of an individual human, it is widely acknowledged that many exposures will either have healthful effects or have no plausible impact on the future well-being of that individual human. Thus, we herein offer the inverse view that taken *in toto*, whether adverse, salutary or neutral, the effects of diverse exogenous exposures alter the developmental trajectories of each future individual human and consequently provide countless patterns of individualization of all future humans (Figure 1). In Figure 1, we have elected to illustrate our framework of pre-birth human individualization during development as a fractal drawing. We suggest that given the applicability of fractal models to multiple biological systems such as cardiac function (Bassingthwaighte and van Beek 2002), the lung (Weibel 1991), and even the entirety of life itself (Wong and Rosindell 2021), that the human individualization framework would be a good subject for application of fractal mathematics in non-deterministic modeling.

After implantation, the fetal environment and the fetal developmental trajectory is understood to be dependent upon maternal metabolism (nutritional adequacy, excesses or inadequacies), intentional exposures (dietary choices, personal habits, substance use or abuse, etc.), environmental/unintentional exposures (physical, chemical or infectious agents and familial and socioeconomic stressors), as well as maternal pre-pregnancy comorbid diseases and obstetrical disorders such as gestational diabetes, preterm labor, and early or late onset preeclampsia. All of these factors (Hughes and Waters 2016, see multi-authored chapters 3-10) may influence fetal development and thereby move the fetus along different developmental paths than is followed by others. Once again, each of these types of exposure during development modify that future human and diversifies the spectrum of persons who later enter society via parturition and livebirth.

There are a number of classes of exposures that are well-known to affect human development prior to livebirth. Some of these prenatal exposures are quite specific such as drugs prescribed to pregnant women to treat an underlying disease (Dutta 2015; Bastow et al. 2017); while others are environmental such as inhaled particulates that appear to adversely affect infants’ respiratory and immune systems, brain development, and cardiometabolic health (Johnson et al. 2021). Additionally, there are many exposures that are not proven with certainty to affect human prenatal development but are widely thought to be probable or possible human teratogens/developmental toxicants. The following are brief profiles of the key classes of such developmentally influential agents.

Mutagens

All humans are exposed to mutagens (American Cancer Society 2021) including oxidative stress, ionizing radiation, naturally occurring compounds such as mycotoxins as well as environmental contaminants and pharmaceutical agents. Exposures to mutagens and consequent stochastic mutagenic effects (Verheyen, van Deun, and van Miert 2017) during the stages of parental gametes, zygote, embryo and fetal intervals are a source of *de novo* mutations that are acquired differences in an individual's genome. These individualization effects are dependent upon the several characteristics of the exposure such as the compound or compounds, the dose, the duration, the timing during developmentally sensitive windows, and the individual's or maternal genetics that may modify resistance to or susceptibility to the effects of mutagens in various tissues and organ systems.

Prior to fertilization, the individuality of a potential human derives from the genetic diversity among the oocytes and spermatozoa that were produced by the potential parents. Obviously, the genetics of the potential mother and father are profoundly important in determining the spectrum of individual possibilities for that potential human. Another source of individuality can derive from the age of the parents, particularly the father. The reasoning is that the prolonged decades of sperm production offer more opportunities for *de novo* mutations to occur and be present in spermatozoa that may participate in fertilization of an oocyte (Osumi and Tatehana 2021).

Non-Mutagens

Some chemical exposures are intentional such as use of medicinal drugs or substances that are recreational or addictive that may be legal or illicit. Maternal exposures to these classes of compounds during pregnancy are known in many instances to produce adverse effects on the embryo or fetus. Less clear-cut but potentially important are exposures to these classes of bioactive chemicals of either parent prior to or during gametogenesis, fertilization, implantation and embryonic stages of development even prior to awareness of pregnancy.

Since it is widely reported that only about one half of all pregnancies are planned, a vast majority of women take at least one prescription drug during pregnancy, and approximately two thirds take a medicinal drug of some sort during the first trimester. There are numerous pharmaceutical drugs that have been reported to cause birth defects when exposures occurred *in utero* (Capra et al. 2013; Dutta 2015; Bastow et al. 2017). Even for common over-the-counter medications such as those containing acetaminophen (paracetamol), there is justification for considering that fetal developmental effects on neurological, reproductive and urogenital systems may occur (Bauer et al. 2021). Some uncertainty about associating prescription or over-the-counter medication use with developmental effects is valid because the mother typically has an active disease or undiagnosed signs and symptoms, any of which may present certain risks *per se* to the fetus; then the usage of a drug is superimposed in that setting. Nonetheless, regulatory authorities require manufacturers to report such adverse events through safety reporting systems and such data demonstrate to some extent the potentialities for effects in the offspring.

The other prominent class of voluntary chemical exposures that could impact development *in utero* is recreational or addictive substances. As noted currently by the U.S. National Institute on Drug Abuse (2021), these include marijuana (cannabis), stimulants (cocaine and methamphetamine), MDMA (3,4-Methyl​enedioxy​methamphetamine, Ecstasy, Molly), opioids (heroin, diverted prescription opiates), alcohol (ethanol) and nicotine (tobacco products and e-cigarettes). The scientific literature demonstrating the impact of these classes of exposures and the broad range of developmental effects is truly massive (NIDA 2021) and unequivocal.

Less certain but of potential significance is the suggestive evidence from a number of research reports showing that exposures that precede the fetal interval may pose an explicit morphogenic developmental risk or have a physiogenic effect that only manifests in the offspring long after livebirth. We shall cite one of each for illustration.

First, in a recent meta-analysis, Zhang et al. (2019) studied the relationship between parental alcohol exposure and risk of congenital heart disease (CHD) in their offspring. In the pooling of data from more than 50 studies with >40,000 CHD cases and >290,000 controls, there was the expected finding of an increased risk with maternal alcohol exposures [odds ratio (OR) = 1.16; 95% confidence interval (CI): 1.05–1.27] but also with paternal (OR = 1.44; 95% CI: 1.19–1.74) alcohol exposures. To the best of our knowledge, the molecular or cellular mechanisms underlying this reported risk are unknown.

Second, Northstone et al. (2014) used the Avon Longitudinal Study of Parents and Children’s questionnaire data on smoking and smoking onset from >9800 fathers and the data regarding growth of their children from 7–17 years. In brief, after adjusting for potential confounders, the investigators found that for the men who reported regular smoking at <11 years of age, the adjusted mean differences in BMI, waist circumference and total fat mass in their sons were significantly greater from age 13 onwards. From the concept that smoking by boys in mid childhood may contribute to obesity in adolescent boys of the next generation (Northstone et al. 2014), Hammer et al. (2021) recently reported data from their work in an animal (mouse) model offering a degree of mechanistic explanation for non-genomic transmission of such observations about paternal physiogenic effects on their offspring as follows: “miRNAs in the plasma microenvironment of spermatozoa may represent a mechanism for transmittable epigenetic changes to offspring and development of metabolic or respiratory diseases, further highlighting paternal smoking as potential risk factor for offspring’s health.” These data strengthen the idea that tobacco smoking by human male teenagers increases the risk of overweight and obesity in their male offspring.

Parental Diseases

Numerous chronic or recurrent diseases occur in women who become pregnant, sustain the pregnancy, and undergo labor and delivery. The range of such concurrent illnesses that could potentially impact growth and development of each future human was demonstrated by Jolving et al. (2016) in their nationwide (Denmark) registry-based cohort study that included all women who gave birth (> 1.3 million) between 1989 and 2013. These investigators specified 23 maternal chronic diseases within the decade preceding childbirth. While noting that the overall prevalence of maternal chronic disease increased from 3.71% in 1989 to 15.76% in 2013, the ten most prevalent diseases during pregnancy were chronic lung disease/asthma (1.73%), thyroid disorders (1.50%), anxiety and personality disorders (1.33%), mood disorders (0.74%), epilepsy (0.69%), inflammatory bowel diseases (0.67%), polycystic ovarian syndrome (0.52%), diabetes mellitus (0.48%), hypertension (0.43%) and rheumatoid arthritis (0.38%).

While much remains unknown about the potential impacts of many such comorbid conditions on a fetus during gestation, several maternal diseases that frequently occur during pregnancy are known to impact fetal development, ofttimes posing risks to normal *in utero* growth and development. To the extent that potential fetal developmental effects of medications used to treat such diseases can be assessed and set aside, there are still clear attributable risks to the fetus if the gravida has one or more comorbid diseases. Such demonstrated risks include fetal growth (small for gestational age/low birth-weights or high birth-weights) but also metabolic and neurocognitive effects in the neonate and the child. For example, associations of maternal comorbidities during pregnancy and perinatal and childhood outcomes include (Capra et al. 2013; Lahti-Pulkkinen et al. 2020) the following:

* Maternal depression with low birth-weight infant and later central adiposity in the child;
* Maternal diabetes (type 1, type 2 or gestational), hyperglycemia or obesity with high birth-weight infant and later metabolic syndrome and obesity in the child;
* Maternal overweight/obesity with higher likelihood of autism spectrum disorders or neurodevelopmental delays;
* Maternal asthma (with exacerbations) with increased risk of preterm delivery and low birth-weight infant (particularly in males);
* Maternal sleep deprivation and sleep-related breathing disorders with low birth-weight infant (small for gestational age) and a higher risk of mortality;
* Maternal anemia with low birth-weight infant (intrauterine growth retardation) and increased risk of preterm delivery; and
* Maternal hypertensive disorders of pregnancy (gestational and chronic hypertension, preeclampsia) with higher likelihood of childhood mental disorders.

While it may seem intuitive that maternal diseases during pregnancy could impact outcomes of her infant, some data show that paternal health also influences the health of his infant. It is reasonable to suppose that the father’s health could be a genetic precursor of sorts for his infant or that cohabitation of the two parents might lead to predisposing environmental effects on their offspring. However, at least some interesting correlations that may be causations were suggested by Kasman et al. (2020) in their inquiry about whether prepartum and neonatal outcomes are associated with pre-existing paternal health factors. In this retrospective cohort study in the United States of children born between 2009-2016, paternal health status as reflected in diagnoses of various chronic diseases was compared to the primary outcome of preterm birth (meaning live birth before 37 weeks), as well as several secondary outcomes including low birth-weight, neonatal intensive care unit (NICU) stay, gestational diabetes, preeclampsia, eclampsia, and length of maternal stay. By use of a research database covering reimbursed health care claims data on inpatient and outpatient encounters through employment-sponsored health insurance, the investigators assessed 785,809 singleton live births, with 6.6% born preterm.

Kasman et al. (2020) reported, “The presence of paternal comorbidities was associated with higher odds of preterm birth, low birth-weight (LBW), and NICU stay. After adjusting for maternal factors, fathers with most or all components of the metabolic syndrome had 19% higher odds of having a child born preterm (95% CI 1.11–1.28), 23% higher odds of LBW (95% CI 1.01–1.51), and 28% higher odds of NICU stay (95% CI 1.08–1.52). Maternal morbidity (e.g., gestational diabetes or preeclampsia) was also positively associated with preconception paternal health.” These findings suggest but do not causally establish that preconception paternal comorbidities may modestly influence obstetrical and neonatal outcomes.

In addition to those parental disease and drugs exposures, each potential human is subject to numerous other chemical, social, stochastic obstetrical and microbiological exposures that are known or suspected to impact human embryonic/fetal development. It is not possible to fully review all of possible embryonic/fetal exposures in this document, but we will describe a few notable classes.

Environmental Chemicals

There are hundreds of naturally-occurring and man-made compounds that have been demonstrated to be present in either amniotic fluid (Foster et al. 2000; Hughes et al. 2001; Foster et al. 2002; Dusza et al. 2022) or umbilical cord blood (Wang et al. 2021), raising the reasonable prospect that at least some of them may influence development. One prominent group of compounds has been named “endocrine-disrupting chemicals'' (EDCs) which means “an exogenous chemical, or mixture of chemicals, that can interfere with any aspect of hormone action (Endocrine Society 2018).” There is now broad agreement but not consensus that “Individuals and populations are exposed to EDCs, and common non-communicable diseases have been associated with environmentally-relevant doses of EDCs in human epidemiological studies…It is now well established that developmental exposure to EDCs can alter the epigenome of offspring, affecting gene expression and organogenesis, thereby altering an organism's sensitivity to disease later in life (Endocrine Society 2018).” More recent research into the potential neurodevelopmental effects of EDCs (Lopez-Rodriguez et al. 2021), suggest that some effects may include alterations in brain development that advance or delay puberty or alter neuroendocrine control of reproduction thus impairing fertility. Various data suggest that neurodevelopmental effects of EDCs may occur via action on steroidal and non-steroidal receptors but also via alterations in enzymatic, metabolic and epigenetic and other cellular pathways during development (Lopez-Rodriguez et al. 2021). It may be possible to link such mechanistic complexity of EDC actions to various individual neuropsychiatric outcomes by use of network analysis tools. In a new paper, Raja et al. (2022) report that such an analysis seems to show that genes, receptors and signaling pathways interact as a consequence of exposures to EDCs and in turn are associated with disorders such as major depression, alcoholism, psychotic disorders, autism spectrum disorder, attention-deficit/hyperactivity disorder (ADHD), cerebral palsy, and sex-specific aggressive and emotional behavior.

Other Environmental Stressors

Maternal environmental stressors (natural disasters; famine, social stressors) also influence development of her offspring. Tragic large-scale disasters have served as natural (or man-made) experiments wherein many pregnant women were exposed to various forms of deprivation or other stressors, and subsequent assessments of their offspring have shown a number of important health effects.

One such well-recognized event was the Dutch famine of 1944-1945. Even now, decades later, additional reports are being published that demonstrate the life-long persistence of the *in utero* developmental effect(s) that occurred. Lumey et al. (2021) analyzed the heights and weights of 371,100 men in the Netherlands when they were examined for military service at age 19 years. The men born between 1943 and 1947 either did or did not experience prenatal exposure to the Dutch famine. These investigators found that there was an overall 1.3-fold increase in the risk of being overweight or obese at age 19 after prenatal famine exposure in early gestation, and an attendant 30% increase in overall mortality through age 63 relative to those with a normal BMI.

A second such large-scale disaster was the 1998 Quebec Ice Storm. Within the last few years, Paxman et al. (2018) sought to gain some mechanistic insights into the physiological phenotypes seen in the population exposed *in utero* by use of proton nuclear magnetic resonance spectroscopy to analyze urinary metabolomes of male and female adolescents. Overall, these investigators found that higher prenatal stress exposure led to alterations in metabolic pathways involved in energy metabolism and protein biosynthesis; findings that are consistent with dysregulation as would be expected in insulin resistance, diabetes, and obesity.

Finally, a third such event was the Great Tangshan Earthquake (China) in 1976. In this instance, another recent study by Guo et al. (2019) assessed data from >94,000 Chinese individuals born between 1975 and 1979. The investigators studied the relationship between the occurrence of schizophrenia (diagnosed by psychiatrists) and earthquake severity by seismic intensity. In brief, in comparison to an unexposed cohort, the cohort exposed to the earthquake *in utero* had higher risk of schizophrenia (odds ratio, 3.38; 95% CI 1.43–8.00). Notably, earthquake exposure during the first trimester of pregnancy showed a further increased risk of adulthood schizophrenia (odds ratio, 7.45; 95% CI 2.83–19.59).

Though such disasters illustrate the impact that external factors may have on development, societal elements that broadly affect many more individual future humans are embedded in the concept of socio-economic status (SES) as a summary of the availability of material and social resources to any individual. Childhood SES is one of the strongest predictors of lifelong well-being and appears to be associated with the duration and functional complexity of individual brain development (Tooley et al. 2021).

The cellular and molecular mechanisms that mediate such effects of SES or other social factors such as familial adversity are not fully understood, but epigenetics appear to play an important role (Tremblay et al. 2016; Tremblay et al. 2018). As noted by Tremblay et al. (2016);

…there is now emerging evidence that early social-familial adversity leads to long lasting epigenetic alterations. These alterations may influence brain development, and, consequently, the ability to learn to regulate and control aggressive behaviour…the finding that many of these biological factors involved in chronic physical aggression develop very early (i.e., before birth), highlights the need to not only study the impact of the early postnatal environment on physical aggression, but also to take into account what is happening between conception and birth.

Stochastic Obstetrical Factors

Other variables that impact development of some individual future humans are stochastic obstetrical factors. There are occasional presumably random events related to location and qualitative aspects of implantation and thus placentation *per se*. For example, if random implantation occurs over an underlying uterine leiomyoma (fibroid), then as the pregnancy progresses, that fetus may be subject to reduced placental perfusion or placental abruption events that could impact growth *in utero*, lead to premature delivery or pose a risk of hemorrhagic compromise or even stillbirth. Another variable that may be random or iatrogenic as part of infertility therapies is twinning, or higher multiple birth. This latter random pre-birth impact on the potentialities of one identical twin versus the other, has been convincingly demonstrated by Groene et al (2022). These investigators have recently reported on their study of monochorionic diamniotic twins (MCDA) with selective fetal growth restriction (sFGR). They found that "In MCDA twins with sFGR, the smaller twin presents with a lower intelligence quotient across all indexes and an increased rate of mild NDI [neurodevelopmental impairment] compared with the larger co-twin. To our knowledge, we are the first to show that FGR poses a substantial risk for long-term neurodevelopment in this unique identical twin model controlling for maternal, obstetrical, and genetic factors."

Fetal and Maternal Microbiomes

New scientific discoveries demonstrate the impact of fetal and maternal microbiomes (Han et al. 2021) on prenatal development and perinatal outcomes. Two key points are that there is a fetal microbiome (Mishra et al. 2021), and the maternal vaginal microbiome influences the risk of preterm birth (Flaviani et al. 2021).

The long-held “sterile womb” dogma has been fading as evidence for an *in utero* colonization hypothesis has become more substantiated (Perez-Muñoz, et al. 2017). New data show that fetal immunological development *in utero* at least in part depends upon prepartum exposure of each fetus to microbes as early as the second trimester; from Mishra et al. (2021):

The events occurring during fetal gestation are essential for the overall development and growth of the individual…Various studies have recently suggested that certain antigens as well as bacterial entities may cross the placental barrier and make their way to fetal organs…these findings have wider implications in understanding the key factors involved in fetal immune system development and priming *in utero*, which may set the basis for life-long health and immunity of the organism…the existence of a spatially diverse microbial signal in fetal tissues, their ability to culture-expand anaerobically, and the presence of microbial antigen-specific memory T cell activation, are difficult to reconcile with either systematic biases or random noise. Collectively, our data suggest a low but consistent presence of microbes in at least some of the healthy human fetuses in the 2nd trimester of gestation.

While there is wide acceptance in obstetrics that vaginal organisms may contribute to ascending infections that produce chorioamnionitis and preterm labor and deliveries, new data show that even in the absence of intrauterine infections, the maternal vaginal microbiome influences the risk of preterm birth (Flaviani et al. 2021). In their study of spontaneous preterm birth, Flaviani et al. (2021) studied the interactions between the cervicovaginal metabolic environment and microbiota in tandem with the host innate immune response in a prospective United Kingdom (UK) longitudinal cohort of pregnant women. Analysis of cervicovaginal samples (10–15+6 weeks) identified potentially novel interactions between risk of spontaneous preterm birth (sPTB) and microbiota, metabolite, and maternal host defense molecules in an ethnically heterogeneous pregnant population (n = 346 women; n = 60 sPTB < 37 weeks’ gestation, including n = 27 sPTB < 34 weeks). These findings indicate that the maternal microbiome may poise a pregnancy to either be more likely to go to term, or to deliver prematurely and thereby impact an individual neonate and modify its post-natal developmental trajectory and ofttimes compromise one or more of its life-long functional outcomes.

All of these sources of developmental diversification of individual humans that span the time and events from maternal and paternal gametogenesis across pre-fertilization, fertilization, implantation and embryonic and fetal development up to parturition, provide the biomedical background of processes and events that largely determine the characteristics and potentialities of each person at the time of birth.

**The Third Discrete and Blatant Event of Parturition and Birth**

The event that introduces a human into society is parturition and livebirth, and this process presents its own set of challenges that may make a penultimate impact on the developmental outcome of the neonate. For the fetus, several maternal medical and obstetrical risk factors pose risks that may influence the infant’s lifelong health and functional status in diverse ways.

In High Income Countries (HIC), some of the common maternal factors at the time of parturition that impact the neonate are hypertensive disorders of pregnancy (including preeclampsia), age, weight status, diabetes (pre-existing or gestational), substance use, depression, breech presentation and previous Cesarean birth(s) (Scrimshaw and Backes 2020). Among the most dangerous obstetrical complications during labor and delivery for the fetus are uterine rupture, shoulder dystocia, umbilical cord prolapse, chorioamnionitis and fetal macrosomia.

In Low and Middle Income Countries (LMIC), the recent study by Baguiya et al. (2021) show the devastating impact of maternal pre-existing conditions and suspected or confirmed infections on neonatal outcomes. This multinational team of investigators conducted a study in 2017 in 408 hospitals in 43 LMIC in all WHO regions. Women (n=1219) with suspected or confirmed infection during pregnancy at 28 weeks or more of gestational age were followed, along with their infants, up to day 7 postpartum. Neonatal Near Miss (NNM) cases were defined by the criteria of birth-weight <1750 grams, gestational age at birth between 28 and 33 weeks, 5 min APGAR score <7, or use of any of several acute interventions (e.g., parenteral antibiotics, ventilation support, Intubation at birth or other medical or surgical interventions). These investigators reported neonatal outcomes to be

1. 64% (n=780) babies alive without severe complications,
2. 25.9% (n=316) were NNM cases and
3. 10.1% (n=123) perinatal death (stillbirth and early neonatal death);

and commented “Overall, one-third of births were adverse perinatal outcomes. Pre-existing maternal medical conditions and severe infection-related maternal outcomes were the main risk factors of adverse perinatal outcomes."

In multiple ways, whether births occur in HIC or LMIC, any of these peripartum risks may impact the fetus/neonate by causing cerebral palsy, Erb's palsy, hypoxic ischemic encephalopathy ("HIE") (perinatal asphyxia), cerebral hemorrhages, hematomas or periventricular leukomalacia ("PVL") as seen in premature infants. If PVL (which can lead to cerebral palsy or epilepsy) is seen as an overt consequence of premature birth, there is strong evidence of more subtle central nervous system developmental effects as well, since a recent study in a cohort of >4 million persons found that preterm and early term birth were associated with significantly increased risks of autism in boys and girls (Crump, Sundquist and Sundquist 2021).

In summary, all of these antecedent diverse, mostly adverse, effects change the life-long trajectories of countless humans in multiple ways prior to birth. Humans are individualized by endogenous genetic and epigenetic events but also by effects of and responses to exogenous exposures within developmentally sensitive interval(s). Developmental exposures of potential humans to multiple diverse exogenous factors means that morphogenesis and physiogenesis of every embryo/fetus possesses individualized attributes for its future lifespan.

**How Do Medical and Scientific Research Guidances Relate to Our Scientific and Ethical Framework of Prepartum Human Development?**

In historical terms, as human *in vitro* fertilization procedures were developed and procedures were regularized in this area of medicine, reviews were conducted by multi-disciplinary committees that provided insightful considerations from many diverse perspectives. Two leading examples were those published in the United States (Ethics Advisory Board 1979) and the United Kingdom (Warnock 1984). While the US panel’s report provided careful evaluative remarks on "The Status of the Early Human Embryo" (pages 27-33 and 48-51 in Ethics Advisory Board 1979), the UK panel’s report, widely called “The Warnock Report” also made careful evaluative remarks (pages 60-72 in Warnock for the Committee 1984) and proposed that human embryos should not be sustained *in vitro* for more than fourteen days for any purpose. In some jurisdictions (such as the UK and Australia), this proposal became law (Davis 2019), and in virtually all portions of the globe, this interval became the explicit or *de facto* guidance for all clinics and laboratories that participated in human *in* *vitro* fertilization clinical practice and/or research. In the book *Personhood Revisited* (Jones 2013), Professor Jones reviewed much of the history of in vitro fertilization as its practices developed in the UK, US and other nations. Regarding personhood (page 74), Jones commented that the American Fertility Society Ethics Committee in 1986 agreed that personhood was the status which was acquired during development at a time when protection by society was expected. Also as defined, this equated to the theological concept of ensoulment in regard to the requirement of societal protection. The Committee also considered the basic biological fact that over the first several days after fertilization, it is uncertain how the development of that entity will progress. Outcomes may be an individual human, multiple individual humans (fraternal twinning), a benign hydatitiform mole tumor or a malignant chorioepithelioma tumor. The committee's assessment was "There was general agreement that the earliest possible point in time for the acquisition of personhood – i.e., protection by society – occurred with the appearance of the primitive streak (The President's Council on Bioethics 2002), which itself guaranteed biological individualization and eliminated the possibility of a benign or malignant tumor (Jones 2013, page 74).” This led to the recommendation that 14 days would be the appropriate designated interval.

Over the subsequent decades and particularly in recent years (Davis 2019) there have been countless thoughtful discussions about the “14-day rule;” however, only recently has a pertinent professional scientific society taken the step of formally changing their position. Specifically, in May 2021 the International Society for Stem Cell Research (International Society for Stem Cell Research 2021), issued their “Guidelines for Stem Cell Research and Clinical Translation” and included on page 12 their argument for changing and support for ending the 14 days post-fertilization restriction. As expected, this new position has evoked great interest and commentary among many medical and scientific professionals (Powell 2021; Sawai et al. 2021; Sheng et al. 2021). One such commentary by Mummery and Anthony (2021) noted that considerations are being given to diversifying new guidelines that will hopefully be "fit for purpose," so that the opportunities for scientific discovery are pursued within an explicit and transparent ethical framework. We hope that no matter the perspective of any person or the position of any organization engaged in this renewed discourse about the “14-day rule,” each will duly consider the framework we are presenting herein as they formulate their new or renewed points-of-view.

**Summary and Conclusions**

Personhood is a designation assigned to a living human being by one or more other living human beings, and for newborns, are obviously all older than the designee. In the biomedical context, a living human being can be reasonably well defined, understood and characterized while the superimposed designation of "person" cannot be fully profiled in biological terms. Nonetheless, setting aside some valid discussions about whether members of another species might merit designation as "a person," it is implausible for there to be "a person" in the absence of a living human being. Thus, biological bases are necessarily foundational for developing any construct of when a human being might be deservedly designated as a person. It seems unlikely that many reasoning persons would argue that upon birth, a living infant human being is not a person. The endless debates obviously relate to the criteria or the criterion by which personhood is or might be designated in the pre-birth interval for a developing human.

Much careful thought and debate has been invested in considering whether there is some discrete event or moment that defines without equivocation that point in a developmental trajectory when personhood might be fully assigned. Running somewhat in parallel to that discourse, the concept of more continuous accrual of personhood during pre-birth development cumulatively leading to full personhood, has also been developed and argued.

We argue that it is an ethical imperative to consider more than merely selecting or endlessly debating when a human is also a person. It is also incumbent upon us to include fundamental considerations of the future human potentialities of individual persons that encompass both the duration of life (longevity) and the quality of life, such as health-related quality of life, over that individual’s future lifespan. It seems likely that most persons would want as many newborns as possible to have favorable future potentialities by not being born with or at elevated risks of congenital cytomegalovirus (CMV), *in utero* Zika virus infection, extreme prematurity and its associated risks, fetal alcohol syndrome or exposures to other drugs of abuse *in utero*, major congenital anomalies (cleft palate, spina bifida, others), cerebral palsy, several types of developmental delays in children (cognitive, motor, social, emotional, behavioral or speech delays), predisposal to early-in-life onset of metabolic disorders such as childhood hypertension or other cardiovascular diseases, type 2 diabetes, kidney disease, frailty or obesity, gastrointestinal diseases, immunological disorders, cancers, etc. Myriad variations among persons are a key part of the way in which society is enriched by diversity. At the same time, it is not a eugenics consideration to strive to have the largest number of neonates to have undergone a pre-birth developmental trajectory that offers breadth and depth of future potentialities later in life.

As modern scientific discoveries have revealed demonstrable facts about additional endogenous and exogenous biological processes and events prior to birth, scientific and ethical considerations are pertinent to assess any other discrete or continuing components that contribute to individualization before the societal entry of an individual human by livebirth. We present the endogenous genetic and epigenetic events and exogenous developmental *milieu* processes that, when combined, produce the distinguishing features of a human prior to its entry into society via livebirth. Accordingly, we present the novel argument that there are now not one but two known discrete discreet biological events that are pertinent to determining a future individual’s identity; namely, fertilization plus the additional discrete biological event of epigenetic resetting of that individual’s biological organismic clock to time zero (t=0) at the gastrulation stage (around day 15 of embryogenesis). Additionally those two discrete discreet biological events are immersed in a continual complex developmental process that spans pre-fertilization and gestational intervals that drives individualization of diverse attributes of each future individual human, preceding the discrete and blatant biological event of livebirth and societal entry of that human. During prenatal development, each future human is subject to various and variable exposures of the gravida to multiple physical, chemical, biological and social factors as well as to its own unique maternal *in utero* environment. These diverse exogenous exposures of every embryo/fetus influence its morphogenesis and physiogenesis thereby individualizing its future attributes, health and functional well-being across its individual human lifespan within society. Our proposed framework as profiled in Table 1 and illustrated in Figure 1, is based on the biological facts spanning pre-fertilization and prenatal developmental discrete events and processes and implies that personhood should be incrementally attributed and societal protections for potential humans should be graduated and applied progressively across the entire human developmental pre-birth timespan.

**Author Contributions**

C.L.H. and G.C.H. jointly conceived the key concepts over an extended series of discussions in 2020, 2021 and 2022. C.L.H. researched the biomedical literature and wrote and edited the manuscript. G.C.H. researched the bioethics literature and wrote and edited the manuscript. C.L.H. is the guarantor of this work and, as such, had full access to all the cited literature and takes responsibility for the integrity of the information presented. Both authors read and approved the final manuscript. Both authors declare that they have no competing interests.

**References**

American Cancer Society. Known and probable human carcinogens. 2021. *Cancer.org*: 1-18.

Baguiya, A., M. Bonet, J. Cecatti, et al. 2021. Perinatal outcomes among births to women with infection during pregnancy. *Archives of Disease in Childhood* Epub ahead of print: 22 SEP 2021. doi:10.1136/archdischild-2021-321865.

Bassingthwaighte, J., and J. van Beek. 2002. Lightning and the heart: fractal behavior in cardiac function. *Proceedings of the Institute of Electrical and Electronics Engineers* August 6; 76(6): 693–699. doi:10.1109/5.4458.

Bastow, B., J. Holmes, F. Talavera, et al. 2017. Teratology and drug use during pregnancy. *emedicine.medscape.com* Article 260725: 1-24.

Bauer, A., S. Swan, D. Kriebel, et al. 2021. Paracetamol use during pregnancy - a call for precautionary action. *Nature Reviews Endocrinology* published online 23 SEP 2021 pp. 1-10.

Boskovic, A., and O. Rando. 2018. Transgenerational Epigenetic Inheritance. *Annual Review of Genetics* 52: 21-41.

Capra, L., G. Tezza, F. Mazzei, and A. Boner. 2013. The origins of health and disease: the influence of maternal diseases and lifestyle during gestation. *Italian Journal of Pediatrics* 39(7): 1-12.

Cavigelli S, J. Leips, Q-Y. Xiang, D.Lemke, and N. Konow. 2021.Next steps in integrative biology: mapping interactive processes across levels of biological organization. *Integrative and Comparative Biology* 0(0): 1–9. <https://doi.org/10.1093/icb/icab161>.

Crump, C., J. Sundquist, and K. Sundquist. 2021. Preterm or early term birth and risk of autism. *Pediatrics* 148(3):e2020032300.

Davis, C. 2019. The boundaries of embryo research: extending the fourteen-day rule. *Bioethical Inquiry* 16:133–140. <https://doi.org/10.1007/s11673-018-09895-w>

de Magalhães J., and J. Wang. 2019. The fog of genetics: what is known, unknown and unknowable in the genetics of complex traits and diseases. *EMBO reports* 20 Article e48054: 1-2.

Dugas, C., and Slane V. Miscarriage. 2021. *NCBI Bookshelf. A service of the National Library of Medicine, National Institutes of Health. StatPearls.* Treasure Island (FL): StatPearls Publishing; Last Update: June 29, 2021. <https://www.ncbi.nlm.nih.gov/books/NBK532992/>

Dusza, H., K. Manz, K. Pennell, R. Kanda, and J. Legler. 2022. Identification of known and novel nonpolar endocrine disruptors in human amniotic fluid. *Environment International* 158: 106904.

Dutta, S. 2015. Human teratogens and their effects: a critical evaluation. *International Journal of Information Research and Review* 2(03): 525-536.

Dworkin, R. 1993. *Life’s Dominion: An Argument about Abortion and Euthanasia.* pg. 10. London, UK. Harper Collins Publishers.

Endocrine Society. Position statement: endocrine-disrupting chemicals, 2018. *Endocrine.org* May 2018: 1-5.

Ethics Advisory Board. 1979. HEW support of research involving human in vitro fertilization and embryo transfer. *Department of Health, Education and Welfare* 04 MAY 1979.

Flaviani, F., N. Hezelgrave, T. Kanno, et al. 2021. Cervicovaginal microbiota and metabolome predict preterm birth risk in an ethnically diverse cohort. *JCI Insight* 6(16) e149257: 1-16.

Foster, W., S. Chan, L. Platt, and C. Hughes. 2000. Detection of endocrine disrupting chemicals in samples of second trimester human amniotic fluid. *Journal of Clinical Endocrinology and Metabolism* 85: 2954-2957.

Foster, W., C. Hughes, S. Chan, and L. Platt. 2002. Human developmental exposure to endocrine active compounds. *Environmental Toxicology and Pharmacology* 12(2): 75-81.

Greasley, K. 2017. *Arguments about Abortion.* Pg 7. Oxford, UK: Oxford University Press.

Grone, S,. J. Koen, J. Stegmeijer, et al. 2022. Long-term effects of selective fetal growth restriction (LEMON): a cohort study of neurodevelopmental outcome in growth discordant identical twins in the Netherlands. *Lancet Child Adolesc Health* Published Online July 21, 2022 <https://doi.org/10.1016/S2352-4642(22)00159-6>.

Guo, C., P. He, X. Song, and X. Zheng. 2019. Long-term effects of prenatal exposure to earthquake on adult schizophrenia. *The British Journal of Psychiatry* 215: 730–735.

Hammer B., L. Kadalayil, E. Boateng, et al. 2021. Preconceptional smoking alters spermatozoal miRNAs of murine fathers and affects offspring’s body weight. *International Journal of Obesity* 45: 1623–1627.

Han, S., C. Ellberg, I. Olomu, and A. Vyas. 2021. Gestational microbiome: metabolic perturbations and developmental programming. *Reproduction* 162: R85–R98.

Haniffa, M., D. Taylor, S. Linnarsson, B. Aronow, et al. 2021. A roadmap for the human developmental cell atlas. *Nature* 597: 196-205.

Heard, E., and R. Martienssen. 2014. Transgenerational epigenetic inheritance: myths and mechanisms. *Cell* 157(1): 95–109.

Hughes, C., W. Foster, S. Chan, et al. 2001. Extrapolation of rodent studies on amniotic fluid contaminants to human populations. *Human and Ecological Risk Assessment* 7(5): 979-1002.

Hughes, C., and M. Waters (eds). 2016. *Translational Toxicology: Defining a New Therapeutic Discipline*, Molecular and Integrative Toxicology, New York, NY: Humana Press. 380 pages.

International Society for Stem Cell Research. 2021. ISSCR guidelines for stem cell research and clinical translation. *www.isscr.org* Version 1.0, May 2021.

Johnson, N., A. Hoffmann, J. Behlen, et al. 2021. Air pollution and children’s health – a review of adverse effects associated with prenatal exposure from fine to ultrafine particulate matter. *Environmental Health and Preventive Medicine* 26(72):1-29.

Jones, H. W. 2013. *Personhood Revisited*. Minneapolis, United States: Langdon Street Press.

Jolving, L., J. Nielsen, U. Kesmodel, R. Nielsen, S. Beck-Nielsen, and B. Norgard. 2016. Prevalence of maternal chronic diseases during pregnancy – a nationwide population based study from 1989 to 2013. *Acta Obstetricia et Gynecologica Scandinavica* 95: 1295–1304.

Kasman, A., C. Zhang, S. Li, D. Stevenson, G. Shaw, and M. Eisenberg. 2020. Association of preconception paternal health on perinatal outcomes: analysis of U.S. claims data. *Fertility and Sterility* 113(5): 947-954.

Kerckhove L., and S. Waller. 1998. Fetal personhood and the sorites paradox. *The Journal of Value Inquiry* 32: 175–189.

Kerepesi, C., B. Zhang, S-G. Lee, A. Trapp, and V. Gladyshev. 2021. Epigenetic clocks reveal a rejuvenation event during embryogenesis followed by aging. *Science Advances* 7(eabg6082): 1-11.

Lahti-Pulkkinen, M., P. Girchenko, S. Tuovinen, et al. 2020. Maternal hypertensive pregnancy disorders and mental disorders in children. *Hypertension* 75: 1429-1438.

Lopez-Rodriguez, D., D. Franssen, J. Bakker, A. Lomniczi, and A-S. Parent. 2021. Cellular and molecular features of EDC exposure: consequences for the GnRH network. *Nature Reviews Endocrinology* 17: 83-96.

Lumey L., P. Ekamper, G. Bijwaard, G. Conti, and F. van Poppe. 2021. Overweight and obesity at age 19 after prenatal famine exposure. *International Journal of Obesity* 45:1668–1676.

Mishra, A., G. Lai, L. Yao, et al. 2021. Microbial exposure during early human development primes fetal immune cells. *Cell* 184: 3394-3409.

Mummery, C., and E. Anthony. 2021. New guidelines for embryo and stem cell research. *Nature Reviews Molecular and Cellular Biology* 22: 773-774.

NIDA. 2021. Substance use while pregnant and breastfeeding. *National Institute on Drug Abuse* 22 June 2021; <https://www.drugabuse.gov/publications/research-reports/substance-use-in-women/substance-use-while-pregnant-breastfeeding>.

Northstone, K., J, Golding, G. Smith, L. Miller, and M. Pembrey. 2014. Prepubertal start of father’s smoking and increased body fat in his sons: further characterisation of paternal transgenerational responses. *European Journal of Human Genetics* 22: 1382–1386.

Osumi, N., and M. Tatehana. 2021. Transgenerational epigenetic information through the sperm. *EMBO reports* 22(e53539): 1-4.

Palmerola K., S. Amrane, A. De Los Angeles, S. Xu, N. Wanget et al. 2022. Replication stress impairs chromosome segregation and preimplantation development in human embryos. *Cell* 185:1-20.

Paxman, E., N. Boora, D. Kiss, et al. 2018. Prenatal maternal stress from a natural disaster alters urinary metabolomic profiles in project ice storm participants. *Scientific Reports* 8(12932): 1-12.

Perez-Muñoz, M., M-C. Arrieta, A. Ramer-Tait, and J. Walter. 2017. A critical assessment of the “sterile womb” and “in utero colonization” hypotheses: implications for research on the pioneer infant microbiome. *Microbiome* 5(48): 1-19.

Powell K. 2021. What’s next for lab-grown human embryos? *Nature* 597: 22-24.

Raja, G., K. Subhashree, and K. Kantayya. 2022. In utero exposure to endocrine disruptors and developmental neurotoxicity: implications for behavioural and neurological disorders in adult life. *Environmental Research* 203(111829): 1-10.

Sawai, T., G. Okui, K. Akatsuka, and T. Minakawa. 2021. Promises and rules. *EMBO reports* 22(e53726): 1-3.

Scrimshaw, S., and E. Backes for the Committee. 2020. Epidemiology of clinical risks in pregnancy and childbirth. In *Birth Settings in America*, ed. S. Scrimshaw, and E. Backes, 85-111. The National Academies Press, Washington, DC.

Sheng, G., A. Arias, and A. Sutherland. 2021. The primitive streak and cellular principles of building an amniote body through gastrulation. *Science*. 374(6572): doi. 10.1126/science.abg1727

Skogen, J., and S. Overland. 2012. The fetal origins of adult disease: a narrative review of the epidemiological literature. *Journal of the Royal Society of Medicine Short Reports* 3: 59-65.

Soubry, A., S. Murphy, G. Vansant, Y. He, T. Price, and C. Hoyo. 2021. Opposing epigenetic signatures in human sperm by intake of fast food versus healthy food. *Frontiers in Endocrinology* 12(625204): 1-10.

The President's Council on Bioethics, Human Cloning and Human Dignity: *An Ethical Inquiry.* Chapter 6. July 2002.

Thompson, R., and F. Einstein. 2010. Epigenetic basis for fetal origins of age-related disease. *Journal of Women’s Health* 19(3): 581-587.

Tooley, U., D. Bassett, and A. Mackey. 2021. Environmental influences on the pace of brain development. *Nature Reviews Neuroscience* 22: 372-384.

Tremblay, R., L. Booij, N. Provençal, and M. Szyf. 2016. The impact of environmental stressors on DNA methylation, neurobehavioral development, and chronic physical aggression: prospects for early protective interventions. In *Translational Toxicology: Defining a New Therapeutic Discipline*, ed. C. Hughes, and M. Waters, 295- 319. Molecular and Integrative Toxicology, New York, NY: Humana Press.

Tremblay, R., F. Vitaro, and S.Cote. 2018. Developmental origins of chronic physical agression: a bio-psycho-social model for the next generation of preventive interventions. *Annual Review of Psychology* 69:383–407.

Tuscher, J., and J. Day. 2019. Multigenerational epigenetic inheritance: one step forward, two generations back. *Neurobiology of Disease* 132(104591): 1-15.

van Gelder, M., I. van Rooij, R. Miller, G. Zielhuis, L. de Jong-van den Berg, and N. Roeleveld. 2010. Teratogenic mechanisms of medical drugs. *Human Reproduction Update* 16(4): 378–394.

Verheyen, G., K. van Deun, and S. van Miert. 2017. Testing the mutagenicity potential of chemicals. *Journal of Genetics and Genome Research* 4(1): 1-11.

Viguera, A., M. Freeman, L. Góez-Mogollón, et al. 2021. Reproductive safety of second-generation antipsychotics: updated data from the Massachusetts General Hospital national pregnancy registry for atypical antipsychotics. *Journal of Clinical Psychiatry* 82(4): 20m13745.

Wang, A., D. Abrahamsson, T. Jiang, et al. 2021. Suspect screening, prioritization, and confirmation of environmental chemicals in maternal-newborn pairs from San Francisco. *Environmental Science and Technology* 55: 5037−5049.

Warnock, M. for the Committee. 1984. *Report of the Committee of Inquiry Into Human Fertilisation and Embryology Department of Health & Social Security*. London, UK. 103 pages.

Weibel, E. 1991. Fractal geometry: a design principle for living organisms. *American Journal of Physiology.* 261 (*Lung Cellular and Molecular Physiology* 5): L361-L369.

White, F. Personhood: An essential characteristic of the human species. 2013. *The Linacre Quarterly* 80(1): 74–97.

Wong Y., and J. Rosindell. 2021. Dynamic visualisation of million-tip trees: The OneZoom project. *Methods in Ecology and Evolution* 00:1–11.

**Figure, Legend and Table**

Fig. 1 Framework for Sources of Diversity for Developmental Individualization of Potential and Future Humans

Both pre-fertilization (the upright tree) and post-fertilization (the shared trunk and inverted tree) elements illustrate the complexity\* of endogenous and exogenous events and processes by which attributes of personhood are incrementally acquired. The fractal-like elements are intended to be evocative in that future non-deterministic mathematical modeling could be undertaken.

\*The items in the figure are representative, not all-inclusive.

Diagram

Description automatically generated

Table 1. Correlations of Biomedical and Bioethical Features of Human Reproduction and Prenatal Development

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Biomedical Processes and Events | | | | Bioethical Interpretations or Attributions of Personhood | | | |
| Process | **Event** | **Biological Remark** | **Medical Remark** | **Punctualist** | **Associative Comment** | **Gradualist** | **Associative Comment** |
| Integrity of Parental DNA | **-** | Germ cell mutagenesis & protection | - | - | Usually not assessed | - | Usually not assessed |
| Gametogenesis | **-** | Parental genome & epigenome packaged for possible fertilization | - | - | Usually not assessed | - | Usually not assessed |
| - | **Gamete attrition before & after coitus** | Multiple cohorts of oocytes per month for single ovulation & only one spermatozoan per fertilization | - | - | Usually not assessed | - | Usually not assessed |
|  | **Fertilization** | Zygote forms; may or may not give rise to fraternal twins | - | Some may attribute full personhood | - | May attribute a degree of personhood | - |
| Pre-implantation embryo attrition | **-** | Plausibly occurs in spontaneous fertilizations, but not yet proven | High rate of demise of IVF embryos due to DNA replication errors | - | New science, not yet assessed | - | New science, not yet assessed |
| - | **Implantation** | Endometrium must be properly “prepared” for implantation to occur *in utero* | a) Some are ectopic; b) others are “biochemical” pregnancies only; c) others become spontaneous or inevitable abortions | Some may attribute full personhood | Note that implantation of a zygote into the endometrium is the classical definition of “conception” | May attribute a modestly greater degree of personhood | - |
| Post-implantation embryonic development to primitive streak stage | **Epigenetic resetting of each individual’s organismic clock to time zero (t=0)** | Shown in animal model; stage in human is about day 15 of embryogenesis; identical twinning occurs prior to this gastrulation/ primitive streak stage | IVF embryo Day 14 rule in many jurisdictions fits with these biological insights; process & events are otherwise medically discreet | Usually not addressed | Usually not addressed | May attribute some further modestly greater degree of personhood | New science about epigenetic resetting of each individual’s organismic clock to time zero (t=0), not yet assessed |
|  | **Fetal heart flutter** | - | Requires ultrasound technology; so not observed in many gravidas | May be deemed adequate to attribute full personhood | - | - | Usually not assessed |
|  | **Viable IUP on U/S at 10-12 weeks EGA** | - | Requires ultrasound technology; so not observed in many gravidas | May be deemed adequate to attribute full personhood | - | May attribute some further modestly greater degree of personhood | - |
|  | **Quickening** | - | Range varies, but fetal movement usually felt between 16 & 24 weeks EGA | May be deemed adequate to attribute full personhood | - | May attribute some further modestly greater degree of personhood | - |
|  | **Early second trimester morphometric OB scan** | - | Requires ultrasound technology; usually performed in contemporary OB care but not performed in many gravidas | - | Usually not assessed | - | Usually not assessed |
|  | **Viability of extremely preterm infants with contemporary ICN care** | - | 22 weeks EGA or later | Usually deemed adequate to attribute full personhood | - | Often attributes greater degree of personhood; may be deemed adequate to attribute full personhood | - |
|  | **Viability of most infants without ICN care** | - | 35-37 weeks EGA | - | Usually not assessed | Often attributes greater degree of personhood; may be deemed adequate to attribute full personhood | - |
|  | **Term/near term** | - | Early term EGA: 37 weeks, 0 days to 38 weeks, 6 days.  Full term EGA: 39 weeks, 0 days to 40 weeks, 6 days. | Usually deemed adequate to attribute full personhood | - | Usually deemed adequate to attribute full personhood | - |
|  | **Livebirth of neonate** | - | Births: May be spontaneous, augmented, or operative | Is certainly deemed adequate to attribute full personhood | - | Is certainly deemed adequate to attribute full personhood | - |
|  | **Postnatal life** | Continued growth and differentiation subject to multiple endogenous and exogenous factors | Growth charts, developmental landmarks | - | - | - | Continued acquisition of attributes of personhood |