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Posted Date: 27 June 2025

doi: 10.20944/preprints202506.2258.v1

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The Amniotic Fluid: An Echo of Life's Aquatic Past, And Micro and Nanoplastics Invasion

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Abstract

The hypothesis of abiogenesis posits that life originated in the aquatic environments of early Earth, approximately 3.8-4.0 billion years ago. These ancient oceans, often referred to as the "primordial soup," contained a complex chemical composition influenced by geological, hydrothermal, and atmospheric activities. This solution included dissolved ions such as sodium, chloride, potassium, calcium, magnesium, sulfate, and bicarbonate, determined by geochemical processes. Early cellular life developed mechanisms of homeostasis, maintaining a stable internal environment despite external fluctuations. The cell membrane, composed of a lipid bilayer with embedded proteins, regulated ionic and molecular traffic, maintaining electrochemical gradients essential for cellular functions. Amniotic fluid recapitulates these evolutionary and homeostatic principles, providing an ideal aquatic environment for fetal development. The ionic similarity between amniotic fluid and ancient oceans reflects phylogenetic conservation and ontogenetic recapitulation. Prenatal exposure to environmental toxicants, including metals, organic pollutants, nicotine, and endocrine-disrupting compounds, negatively impacts maternal and fetal health. Micro and nanoplastic (MNPs) derivatives, along with plastic-related substances like phthalates, while colonizing the oceans, enter the human body and occupy organs, including the placenta and amniotic fluid. This highlights the importance of reducing plastic production and environmental release. The One Health concept recognizes the interconnectedness of human, animal, and environmental health, aiming to balance and optimize their health. Amniotic fluid is an evolutionary solution that allows the fetus to thrive in an environment reminiscent of our distant aquatic past, providing stability and protection for its development. Human beings must maintain amniotic fluid that generates health and prosperity, for this reason they must also maintain the oceans in the same way, because both are children of the same space-time.

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The Aquatic Origins of Life

A Geochemical and Physiological Context the prevailing hypothesis for abiogenesis suggests that life originated in the aquatic environments of early earth, approximately 3.8-4.0 billion years ago [1,2]. These ancient oceans, often termed the "primordial soup" or "prebiotic ocean," were characterized by a complex chemical composition, influenced by geological, hydrothermal, and atmospheric activity. The erosion of igneous and metamorphic rocks, volcanic outgassing (emission of CO2, N2, H2S, SO2), and interaction with a largely anoxic but greenhouse gas rich primitive atmosphere contributed to the formation of a dynamic aqueous solution [3].

This solution contained a vast array of dissolved ions primarily sodium (Na^+), chloride (Cl^-), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), sulfate (SO_4^{2-}), and bicarbonate (HCO3^-). It's crucial to note that the relative concentrations of these ions were not arbitrary; they reflected the equilibrium of geochemical processes such as mineral dissolution, salt precipitation, and exchange with hydrothermal sediments. Studies on the geochemistry of ancient oceans suggest that the concentrations of specific ions, in particular Na^+ and Cl^-, were already significant, providing a basic osmotic environment for the first protocells [4]. There is a great association between minerals in **Amniotic fluid** (AF) and fetal development [5].

The Evolution of Homeostasis and the Internal Environment, Claude Bernard's Principle

The earliest forms of cellular life emerging in this aquatic environment developed mechanisms of homeostasis, a concept introduced by Claude Bernard and later expanded upon by Walter Cannon [6]. This principle describes a biological system's ability to maintain a relatively stable internal environment despite external fluctuations. The cell membrane, a semipermeable barrier composed of a lipid bilayer with embedded proteins, became crucial for selectively regulating ionic and molecular traffic. Through ion pumps (e.g., the sodium-potassium Na^+/K^+-ATPase pump) and ion channels, cells could actively maintain electrochemical gradients across the membrane, essential for generating membrane potential, signal transduction, and metabolic functions. The cellular cytoplasm and extracellular fluids in multicellular organisms maintained ionic compositions that mimicked, and in some cases remarkably conserved, those of the ancestral marine environment. This conservation is not accidental; it reflects the co-evolution of enzymatic systems and metabolic pathways that operate optimally under specific ionic concentrations and pH conditions.

Water comprises approximately 60% of the human body; over half of this is located within the cells that constitute organs and tissues, while a significant portion of the remaining water fills the interstitial spaces between cells, akin to seawater permeating through sand grains [7]. The intercellular fluid dynamics play a critical role in influencing cellular behavior. Through the cultivation of microscopic tissue samples, researchers have demonstrated the tissues' response to compressive forces. Specifically, a given tissue exhibits increased flexibility and a rapid relaxation response when the interstitial fluid flows readily; conversely, when cells are compressed and there is limited space available for intercellular fluid movement, the overall tissue displays increased rigidity and resistance to compression.

MNPs suspended in aqueous environments possess the ability to adsorb various pollutants found both in biological systems and aquatic ecosystems, such as oceans and rivers. This phenomenon, known as adsorption, can significantly enhance toxicity levels. Even at low concentrations, environmental pollutants that are not inherently toxic to humans can, upon adsorption to MNPs, result in substantial increase in toxicity [8]. In this context, living organisms display remarkably similar behaviors to those observed in oceanic marine environments.

Maintaining an internal environment similar to the "primordial soup" offered a selective advantage, promoting the stability of biological macromolecules and the efficiency of biochemical reactions. The transition from aquatic to terrestrial life imposed further selective pressures, leading to the development of complex systems (such as kidneys and the cardiovascular system) for regulating fluid and electrolyte balance and conserving body water [9].

Amniotic Fluid and Ocean Fluid: A Fetal Aquatic Microcosm and Ontogenetic Recapitulation

AF represents an extraordinary recapitulation of these evolutionary and homeostatic principles. It is not merely a passive physical cushion but a dynamic homeostatic micro-environment that recreates ideal aquatic conditions for fetal development, finely replicating the principles of primordial aquatic environments. Its composition arises from a complex interplay of maternal and fetal processes. The composition and dynamics of the AF change over time:

1. Early Phase (up to approximately 18 weeks). Amniotic fluid is primarily an ultrafiltrate of maternal plasma, passing across the amniotic membranes and the non-keratinized placental surface. Its composition is nearly isotonic to maternal plasma, reflecting the content of electrolytes and small filterable molecules.

 doi:10.20944/preprints202506.2258.v1

2. Late Phase (after approximately 18-20 weeks). The fetal contribution becomes predominant. The fetus begins to urinate into the amniotic sac and swallow amniotic fluid, creating a constant recirculation. Fetal lung secretions contribute phospholipids and proteins, while secretions from fetal skin (before keratinization) and secretions from the respiratory and gastrointestinal tracts add further components.

The main chemical components of amniotic fluid include:

- Water (H2O): constitutes approximately 98-99% of the volume, serving as the universal solvent for all other substances. Its volume is crucially regulated by the balance between production (fetal urine, lung secretions) and reabsorption (fetal swallowing, transmembranous passage).
- Electrolytes: the concentrations of sodium (Na^+) (approximately 120-130 mEq/L), chloride (Cl^-), potassium (K^+) (approximately 4-6 mEq/L), and bicarbonate (HCO3^-) are finely regulated. They tend to be similar to maternal plasma in the early stages, then slightly decrease with increased fetal urinary output (which is hypotonic). Remarkably, the relative proportions of these ions maintain a notable similarity to dilute seawater, a further confirmation of evolutionary "memory." The pH of amniotic fluid (typically 7.0-7.5) is also regulated to optimize the environment for fetal development, remaining neutral or slightly alkaline, consistent with primordial aquatic environments.
- Proteins: although present in lower concentrations than maternal plasma (approximately 0.2-0.3 g/dL), they include albumins, globulins, transferrin, and other specific proteins (e.g., alpha-fetoprotein, produced by the fetus), with nutritional, osmotic, immunological, and transport functions.
- Carbohydrates: primarily glucose, a fundamental energy source for the fetus. Its concentration is maintained in equilibrium with maternal blood glucose.
- Lipids: play structural roles (e.g., phospholipids, such as lecithin and sphingomyelin, crucial for lung surfactant maturation) and energetic roles.
- Metabolic waste Products: urea, creatinine, and uric acid, derived from fetal metabolism and primarily eliminated through fetal urinary tracts into the amniotic fluid. Their concentrations increase with advancing gestation, reflecting fetal renal maturation.
- Hormones and Growth Factors: a wide range of hormones (e.g., prolactin, cortisol, thyroid hormones) and growth factors (e.g., EGF, IGF) are present in amniotic fluid, regulating the complex processes of fetal differentiation and development.
- Fetal Cells: desquamated from the fetal epidermis, respiratory, and urinary tracts, these cells provide material for prenatal diagnosis (e.g., amniocentesis for karyotyping and genetic analysis) [10].

The ionic similarity between amniotic fluid and terrestrial aquatic environments is not a mere coincidence; it reflects a principle of phylogenetic conservation and ontogenetic recapitulation. The fetus develops in an environment that recapitulates the physicochemical conditions in which our most remote ancestors evolved. This "chemical memory" is a testament to the continuity of evolution and the profound interconnectedness between our physiology and the abiotic conditions that fostered the emergence and diversification of life on our planet. Primary Component of AF is water (approximately 98-99%). Dissolved Substances are electrolytes (such as sodium, potassium, chloride, and bicarbonate), fetal urine, hormones, nutrients, antibodies, and other substances. The composition of the AF changes over time: early in pregnancy, the fluid is mainly derived from maternal plasma, as pregnancy progresses, fetal urine and other fetal products contribute increasingly to the fluid composition. The main functions of AF are protects the fetus, provides essential nutrients, and facilitates the exchange of waste products between the fetus and the mother. Amniotic fluid contains mainly water, but it also includes electrolytes, proteins, lipids, urea, hormones, fetal cells and enzymes. Among electrolytes, the most abundant are sodium, chloride and potassium, as with ocean water. The precise concentrations vary, also depending on the gestational age and geography, but the amniotic fluid is similar in composition to sea water, although with a lower concentration of mineral salts. Approximate composition of the main substances dissolved in the amiotic fluid:

Sodium: present in average concentrations of about 8.3 mg/l

Potassium: is one of the main electrolytes. typically ranges from 2.5 to 6.1 mEq/liter, depending on factors like gestational age and individual variations.

Chloride: present together with sodium, also one of the main electrolytes. The concentration of chloride in amniotic fluid is typically around 101.8 - 109.3 mmol/L. This concentration can vary slightly based on gestational age and individual differences

Calcium: average concentration of about 97 mg/l

Magnesium: average concentration of about 9.8 mg/l

Proteins: amniotic fluid contains proteins, including enzymes and immunoglobulins.

Lipids: important for the development of the fetus, such as lecithins and sphingomyelins, that form the pulmonary surfactant.

Other substances: urea, hormones, fetal cells.

Environmental pollutants...

Currently, the differences in composition of these two fluids, which come from the same "primordial broth", are rather marked (Figure 1).

Amniotic fluid and ocean water share a high water content but differ significantly in their dissolved mineral composition. Amniotic fluid is primarily composed of water with electrolytes and other substances [11] while ocean water contains various dissolved salts, inorganic and organic materials, and gases [12]. Here a more detailed ocean fluid composition:

primary Component is water (approximately 96.5%). Dissolved substances: primarily salts, including sodium chloride, magnesium, calcium, and potassium. it also contains inorganic and organic materials, atmospheric gases, and various trace elements. The composition of ocean water is relatively stable, with a few major ions and a small percentage of other dissolved substances. Function: supports marine life, regulates the Earth's climate, and plays a crucial role in the global carbon cycle [13]. There are some important differences between the two fluids of life: Ocean water has a much higher salinity (salt content) compared to amniotic fluid. Amniotic fluid contains fetal urine, which is absent in ocean water. Amniotic fluid facilitates the exchange of nutrients and waste products between the fetus and the mother, whereas ocean water supports the growth and metabolism of marine organisms.

Seawater is primarily composed of water, approximately 96.5%, the remaining 3.5% consists of dissolved salts and other substances. Various substances are contained in seawater. The average salinity of seawater is about 35 grams of dissolved salts per liter of water (35‰, parts per thousand). The salinity of seawater can vary depending on geographical location and environmental conditions. For example, in areas with high evaporation (such as the Red Sea) the salinity may be higher, while in areas with abundant freshwater inputs (such as near the mouth of rivers) the salinity may be lower. The main dissolved component is sodium chloride, which accounts for about 85% of dissolved salts. Other salts, present in significant concentrations, include magnesium chloride, sulfate, calcium and potassium.

Approximate composition of salts dissolved in the oceans:

Sodium chloride: accounts for the majority of salinity, about 85%

Magnesium chloride: contributes to the slightly bitter taste of seawater. In ocean water, magnesium chloride is present at a concentration of approximately 1.26 g/dm^3. This translates to about 3.7% of the total mineral content of seawater.

 doi:10.20944/preprints202506.2258.v1

Sulphate: present in significant quantities. The concentration of sulfate in the ocean is typically around 28-29 millimolar (mM). This equates to a total of approximately 3.8 x 10^{19} to 3.9 x 10^{19} moles in the ocean. The residence time for sulfate in the ocean is estimated to be around 12.5 million years

Calcium: Important for the formation of the skeletons and shells of many marine organisms.The average concentration of Ca^{2+} (calcium ions) in seawater is approximately 10.28 mmol/kg at a salinity of 35. This corresponds to about 411 ppm (parts per million).

Potassium: another essential element for marine life.The concentration of potassium in typical seawater is approximately 380 mg/L. This translates to about 0.01 M or 10 mM. Potassium is one of the major ions found in seawater, with a relatively stable concentration.

Other substances: the remaining small percentage includes dissolved inorganic and organic materials, particulates, and some dissolved atmospheric gases.

Environmental pollutants... [14].

We have known for a long time that prenatal exposure to widespread environmental toxicants is detrimental to maternal health and fetal development, as well as for the oceans and all the marine life they contain: metals, organic pollutants, nicotine, air pollutants, drugs, determine, depending on their concentrations and the different methods of intake, negative effects on fetal-neonatal development and ocean life [15].

Human exposure to endocrine disrupting compounds (EDCs) is always dangerous for everyone, but timing of exposure is of importance and pregnant women and infants are more vulnerable to EDCs and are at greater risk compared to adults [16,17].

Lately, a new threat has appeared on the horizon of human organisms in formation: micro and nanoplastic derivatives [18] and plastic-related substances such as phthalates [19] they enter the human body through the oral, cutaneous and respiratory routes (Figure 2) and from there occupy various organs and parenchymas, including the placenta [20]. The amniotic fluid [21] and the human milk [22].

This implies that whatever we put into the external environment (oceans) will inevitably be absorbed by our organism, since the interactions between our body and the environment go beyond superficial perceptions. It is the concept of One Health (Figure 3): a collaborative, multi-sectoral, and transdisciplinary approach that recognizes the interconnectedness of human, animal, and environmental health. It aims to sustainably balance and optimize the health of people, animals, and ecosystems, acknowledging that these elements are closely linked and interdependent [23]. The network that unites us to other living organisms and even to inorganic matter is deep, concrete, acquired onto and phylogenetically in a continuous breath that has taken billions of years to arrive at the wonderful current situation [24].

AF, ultimately, is an elegant evolutionary solution, that allows the fetus to thrive in an environment reminiscent of our distant aquatic past, providing the stability and protection necessary for its delicate and complex ontogeny. The presence of different environmental pollutants and especially of plastic material in the amniotic fluid, must lead us to reduce production, futile use mostly disposable, and the release of plastics into the environment. There is a continuous exchange of electrolytes, pollutants, hormones, organic and inorganic material, between the oceans and the amniotic fluid, and also vice versa (Figure1). It is mandatory that human beings, if they want to maintain an amniotic fluid that generates health and prosperity, must also maintain the oceans in the same way, both are children of the same space-time.

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