Fluids: Matter in Motion

The first of two parts

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This topic is filled with potency, inspires me and draws me to peer into the deep well of truth that nourishes my mind with a great tide of information about this amazing, life-giving and sensate substance that we know so well: water.

Despite our intimate familiarity with water, I find much about it to be a mystery and worthy of further study. In this article, I would like to point out the importance of water as it relates to osteopathic philosophy. Then, I would like to characterize water's physical properties, to describe some of the facts about its role on the planet earth and to compare that role to its function within the earth's microcosm, that is, the human body. And finally, I would like to explore how water works as a spiritual force for life.

Osteopathy's Water

Of course, the reason we choose to entertain this topic at all is because of the fundamental relationship fluids have with osteopathy. Andrew Taylor Still, MD, is quoted on this topic in many places in his writings. Commenting about water itself, Dr. Still stated in *Osteopathy, Research and Practice*, "In the union of any two elements we have a cause producing an effect, a new being superior to either element in the compound. Unite hydrogen with oxygen, the result is water, a new being."[1]

In the *Philosophy of Osteopathy*, Still wrote, "If a thousand kinds of fluids exist in our bodies a thousand uses require their help, or they would not appear. Thus to know how and why they help in the economy of life is the study of he who acts only when he knows at what places each must appear, and fill the part and use for which it is designed. If the demand for a substance is absolute, its chance to act and answer that call and obey such command must not be hindered while in preparation, nor on its journey to local destination, for by its power all action may depend. Thus blood, albumen, gall, acids, alkalies, oils, brain fluid and other substances formed by associations while in physiological processes of formation must be on time in place and measured abundantly, that the biogenic laws of nature can have full power with time to act, and material in abundance and of kinds to suit. Thus all things else may be in place in ample quantities and fail because the power is withheld and no action for want of brain fluids with its power to vivify all animated nature."[2]

Here, Dr. Still emphasized the importance of fluids, how they form and how they deliver life giving substances, the correct kinds to the correct places and in the correct amounts. Speaking of brain fluids, he indicated that they have the power to vivify animate beings. Later, Sutherland expanded upon the meaning of this statement. I will leave Sutherland's important comments about water and biological fluids to other references, which are well known to osteopathic physicians who engage the primary respiratory mechanism.

On page 39 in the *Philosophy of Osteopathy*, Still said, "A thought strikes him that the cerebrospinal fluid is the highest known element in the human body and unless the brain furnishes this fluid in abundance a disabled condition of the body will remain. He who is able to reason will see that this great river of life must be tapped and the withering fields irrigated at once or the harvest of health will be forever lost."[3] Later, in the same treatise, he declared, "The brain flushes the nerves of the lymphatics first, and more than any other system of the body."[4] And further, he is quoted, "The lymphatics consume more of the finer fluids of the brain than the whole viscera combined."[5] He also stated, "Finer nerves dwell with the lymphatics than even with the eye."[6] And, "...all...nerves ...drink from the waters of the brain."[7] Of course, then came the statement for which Dr. Still is so often quoted, regarding the importance of another of these fluids, blood, when he said, "The rule of the artery is supreme."[8]

The next comment from Dr. Still provided us his reasoning to employ osteopathic manipulative treatment as it relates to fluids in the body. "I have thought for many years that the lymphatics and cellular system of the fascia, of the brain, the lungs and the heart throughout the whole system of blood supply, do get filled up with impure and unhealthy fluids, long before any disease makes its appearance, and that the procedure of changes known as fermentation, with its electromagnetic disturbances, were the cause of at least ninety percent of the disease...."[9]

With these quotations from our founder, we have the stage set for our exploration into the characteristics of water, to be followed by how water works in physiology and with spirit.

Characteristics of Water

Water is the most common substance on earth. It covers more than 70 percent of the earth's surface. It fills the oceans, rivers and lakes, and is in the ground and in the air we breathe. Water is everywhere.[10]

Wherever water occurs, it tends to take on a spherical form. It envelops the whole sphere of the earth, enclosing every object in a thin film. We see moving water always seeking a lower level, following the pull of gravity. It is earthly laws that cause it to flow, to draw it away from its spherical form and to make it follow a more linear and determined course. Yet water continually strives to return to its spherical form. It finds many ways of maintaining a rhythmical balance between the spherical form natural to it and the pull of earthly gravity.[11]

Ever since the world began, water has been shaping the earth. Rain hammers at the land and washes soil into rivers.

The oceans pound against the shores, chiseling cliffs and carrying away land. Rivers knife through rock, carve canyons and build up land where they empty into the sea. Glaciers plow valleys and cut down mountains.

Water that has seeped into the nooks and crannies of cliffs expands as it freezes, thus cracking the hardest rocks. In this way it starts off the dead, hard element on its way back to life. Through the action of water in the course of time, the rocks crumble to a finer and finer consistency, and they become the basis for plant growth, being received again into the great cycle of living nature. Water destroys the hard rock and thus slowly brings it to life, but at the same time it tames its own surplus energy with what it has again and again deposited in the form of barriers and obstacles in the path of the rushing torrent.[12]

Two kinds of waves are discussed in Theodor Schwenk's book *Sensitive Chaos*, to which additional reference will be made later. One type of wave is propagated through relatively still water, such as a sea or lake, in which the energy of the wave moves through the water without displacing the molecules themselves. The water molecules move in an up-and-down, circular pattern returning to their location once the wave has passed. As these circles that water molecules describe meet the sea floor at the shore, they become elliptical. In this way, the wave then turns into an ebb and flow pattern, commonly encountered at the beach. This source of the ebb and flow pattern will be referred to later.[13]

The second type of wave is in flowing water, in which water molecules are constantly flowing through a relatively still wave. Standing waves are observed in rivers, for instance, downstream from a rock. This is an archetypal principle of all living creation–organic form, in spite of continuous exchange of material, remains intact. This principle is manifested by the continuous replacement of water, air and other substances within each of us, although we remain the same individuals we have always been.

Water is used and reused over and over again–it is never used up. Every glass of water you drink contains molecules of water that have been used countless times before. By one estimate, there are over 332 million cubic miles (1.4 billion cubic kilometers) of water in, on and above the planet. This amount has been constant since the formation of the earth.[14]

How much of the earth's water is fresh? Only about three percent of the earth's water is fresh. About one-half of the earth's fresh water is frozen in icecaps and other glaciers. Glaciers contain as much water as flows in all the earth's rivers in about a thousand years.

Life giving precipitation comes from the atmosphere where only one thousandth of one percent of the earth's water is found, although at one time or another, all the earth's water will have been found to be in the atmosphere. Eighty-five percent of the water in the air comes from evaporation from the oceans. Seventy-five percent of the earth's precipitation falls back into the oceans.[15]

Not only is water the most common substance on earth, it is also the most unusual. Unlike most substances, which contract when they get colder, water expands at temperatures above and below 39°F (4° C). For this reason, ice floats on liquid water. If, instead of floating, ice sank, the earth would become a lifeless, arctic desert. Schwenk comments, "But by floating as ice, water once again reveals that it is its nature to serve life."

Water is the only substance on earth that is naturally present in three different forms–solid ice, liquid water and gaseous water vapor. Liquid water exists between 32°F (0° C) and 212°F (100° C). Ice exists below and water vapor exists above these parameters. Comparing water to dihydrogen compounds of its closest relatives on the periodic chart of the elements, tellurium, selenium and sulfur, we find that these three are all gasses at common earth temperatures, liquefying at -130°F.

The heat capacity of water is the greatest of any substance except ammonia. Nearly five times as much energy is required to turn boiling water into steam than to bring ice to a boil. For water, the heat of fusion (or melting) is 80 cal/g. The heat of vaporization (or condensation) is 540 cal/g. This energy to vaporize or to condense water is used to do work in many man-made machines. In nature, as water vapor condenses to form clouds and fog, and to fall as rain, the heat capacity energy is released creating weather phenomena.

To demonstrate the unusual heat capacity of water, imagine a pound of water, a pound of gold, and a pound of iron–all at absolute zero, -459.67°F. Heating all three substances equally, gold would melt first at 2016°F, but the water would still be at -300°F. Next when the iron began to melt at 2370°F, the ice would finally have reached 32°F.

This characteristic of water helps keep the earth's climate from getting too hot or too cold. Land absorbs and releases heat from the sun quickly. But the oceans absorb and release the sun's heat slowly. So breezes from the oceans bring warmth to the land in winter and coolness in summer.

The most common crystal structure found in ice is five molecules of water forming a tetrahedral pattern. (See Fig. 1)

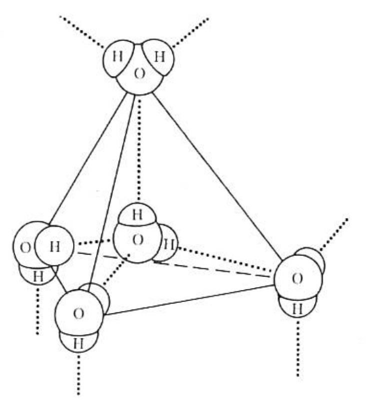

Fig. 1 Arrangement of oxygen atom in ice[+]

The two hydrogen atoms of a particular molecule of water each attract one oxygen atom from two other water molecules, while the single oxygen atom attracts two hydrogen atoms from two other atoms, all by means of hydrogen bonding. There are eight different lattice formations of ice that are known, seven of them produced by increasing atmospheric pressures. The tetrahedral pattern, form I, is the most common.

As ice melts, about 15 percent of the hydrogen bonds break, giving way to a greater density in the liquid phase. Through hydrogen bonding, liquid water has similar associations among its molecules to that of ice. Gaseous water molecules have almost no associations with other water molecules with some rare exceptions of dimers or trimers. Sublimation can and does occur between the solid and gas phases, bypassing the liquid phase.[16]

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Because of the high dielectric constant of water (78.3, relative to 1 for a vacuum), it is able to reduce by approximately a factor of 80 the attractive forces between cations and antions to dissolve salts.[17] Water can dissolve almost any substance, including the hardest of rocks. It carries these dissolved minerals to the sea as it does nutrients to the cells of living things.

Water is a poor electrical conductor, when pure. However, when it contains salts, as it usually does, it conducts electric currents as demonstrated by physiological solutions. These solutions, within biologic systems, mimic the salt concentrations of seawater.

Water's surface tension is extremely high. Because of surface tension, a drop of water attempts to aggregate into a sphere, and with the influence of gravity, will form a teardrop shape when falling through the air, and a circle while resting on a flat surface. Water can support on its surface objects heavier than itself due to this property. Needles, razor blades and insects can float on water. By sticking to cloth, soil and glass, water wets them. Capillary action, another phenomenon of surface tension, affords water and therefore biological fluids the ability to move against gravity, up through soil, into roots and stems of plants and throughout our bodies.

Physiology of Water

Without water, life is unimaginable. In fact every living thing consists mostly of water. Life forms began in water, in the salty water of the sea, from which cells originally acquired their current requisite salt concentrations. Every plant, animal and human being needs water to stay alive. All life processes–from taking in food to getting rid of wastes–require water. Human beings can live without food for more than two months, but they can live without water for only about a week. If the body loses more than 20 percent of its normal water content a person will die painfully.

All living things consist mostly of water. An elephant is about 70 percent water, a potato about 80 percent and a tomato about percent. In the human, water accounts for about 90 percent of the body weight, including around 50 percent contributed by the intracellular compartment, about 15 percent by the interstitial space, and around 5 percent by the vascular system. Human beings must take in about two and one-half quarts (2.4 L) per day.

There is no significant difference between the osmolarity of serum and simultaneously sampled specimens of cerebrospinal fluid or pathological accumulations of ascitic, edematous, pericardial, pleural and synovial fluids. Therefore, we must conclude that, in health and disease, dynamic osmotic equilibrium, or constant water activity prevails, implying that intercompartmental boundaries are freely permeable to water. Water is by far the most abundant molecular species of the body, so body fluids can be characterized as relatively dilute aqueous solutions. Because of the all-pervasive nature of water and its constant activity throughout the body, any disturbance in health relates in some manner to water. Thus, the gray matter of the brain, with its high water content of percent, is much more susceptible to water derangement than bone, in which water content is 44 percent.[18]

Biochemistry of Water

A. The water molecule and hydrogen bonding

The chemical bonds of water bind the two hydrogen atoms extremely tightly to the single oxygen atom, since they share electrons. The oxygen atom has four valence bonds directed nearly tetrahedrally, two of which are taken up by the hydrogen atoms, while the other two remain unoccupied. The hydrogen atoms share one electron each to fill their shell.

Because the oxygen atom is more electronegative, it pulls the hydrogen atoms close to it, about one angstrom unit from the oxygen atom. The hydrogen atoms are so deeply buried in the oxygen to make the molecule almost spherical. To approximate the shape of a water molecule, visualize Mickey Mouse, the ears being the hydrogen atoms, the head being the oxygen atom. The angle between the two hydrogen atoms is 104.5° (See Fig. 2) The two hydrogen atoms tend to occupy one side of the oxygen atom, lending a bipolar charge to the molecule, affording the oxygen a partial double negative charge and each hydrogen a partial positive charge. These polar opposites link water molecules together, through what are called hydrogen bonds, into chains and other geometric arrangements, which create other functional characteristics of water.[19]

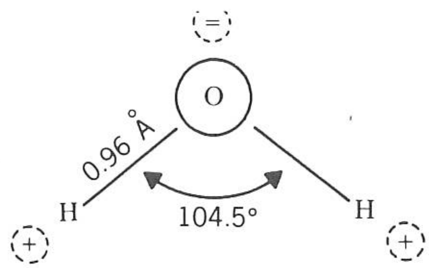

Fig. 2 Water Molecule[+]

At physiological temperatures, hydrogen bonding determine weakly defined tetrahedra-like order that is discernible in 15 percent of cellular water by X-ray and neutron diffraction studies. These studies reveal water molecules exist as a network of severely distorted hydrogen bonds throughout the liquid. The molecules are highly mobile and space-filling in aqueous solutions. Their mobility is determined by the average strength–and hence the length and distortion of the constituent hydrogen bonds. Irregular polygons are evident. Solutes perturb the random pattern of hydrogen bonds in water according to their size, charge, shape and chemical character. At hypotonic concentrations, Na^+ and hydrophobic amino acids reduce the average distortion of hydrogen bonds and diminish the molecular mobility of water, whereas K^+ and hydrophilic amino acids increase hydrogen bond distortion and enhance water mobility.[20]

B. Water of the cytoplasm

The physical properties of the cytoplasm and its effects on the diffusion and binding of macromolecules and vesicles can be largely attributed to water. Classical biochemistry is founded on several assumptions that are valid in dilute aqueous solutions and that are often extended without question to the interior milieu of intact cells. However, the cell's interior departs from the conditions of an ideal aqueous solution. It is clear that the aqueous phase of the cytoplasm is crowded rather than dilute, and that the diffusion and partitioning of macromolecules and vesicles in cytoplasm is highly restricted by steric hindrance as well as by unexpected binding interactions. Furthermore, we now know that the enzymes of several metabolic pathways are organized into structural and functional units with specific localizations in the solid phase. By one estimate, half the cellular protein content, rather than being in solution, may exist in the solid phase.[21]

The high degree to which water is organized within the cell through hydrogen bonding and other forces, such as van der Waals forces, has become generally accepted within the last 15 years. As early as 1940, the famous neuro-physiologist, Sherrington said, "Although it is fluid and watery, most of the cell is not a true solution. A drop of a solution, of homogenous liquid, could not 'live.' It is remote from 'organization.' In the cell there are heterogeneous solutions. The great molecules of protein and aggregated particles are suspended not dissolved. A surface is a field for chemical and physical action. The interior of a pure solution has no surfaces. But the aggregate of surface in these foamy colloids which are in the cell mounts up to something large. The 'internal surface' of the cell is enormous. The cell gives chemical results which in the laboratory are to be obtained only by temperatures and pressures far in excess of those of the living body. Part of the secret of life is the immense internal surface of the cell."[22] As Schwenk pointed out, "...surfaces–both inner and outer ones–are very significant regions of water where rhythmical and formative processes take place."[23]

C. Water and proteins of the cytoplasm

Saenger [26] is quoted as follows, "The three-dimensional structure of every biological macromolecule, be it protein or nucleic acid, is intimately associated with water. Water gives rise to hydrophobic interactions that stabilize the core of globular proteins (oil-drop model) and provide most of the stacking energy in double-helical nucleic acids. Water diminishes charge-charge interactions, and in many proteins it has the role of filling internal cavities. Water molecules cover the surface of proteins and nucleic acids, and they are pushed away if substrate molecules diffuse to active sites or if macromolecules aggregate to form larger complexes."

Urry described, in his paper in the January 1995 issue of *Scientific American*, the dynamics at a subcellular level between water and hydrophobic regions of proteins. We observe in the bottom of a figure in this paper (See Fig. 3), the

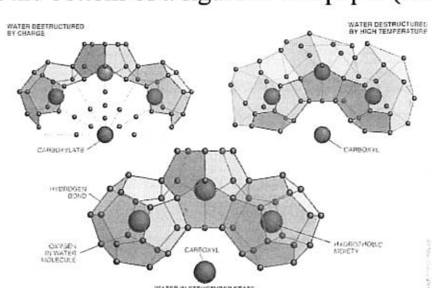

Fig. 3 Structure of water with hydrophobic molecules ++

twelve-sided pentagonal conformation that water assumes to

surround a hydrophobic region of a protein molecule. The other parts of this figure demonstrate the destructuring of this conformation under certain influences.[24] The angle between the two hydrogen atoms of the water molecule, 104.5° (See Fig.2), is nearly equal to the 108° angle constructed between the water molecules of a symmetrical pentagon. Therefore, the hydrogen bonds are only slightly distorted, a preferred condition considering thermo-dynamics and stability.[25]

D. Structured water

Wiggins, in her review article in 1996, classified biological water in two forms, low-density and high-density water. Low-density water is characterized by its separation to allow for the hydrophobic regions of macromolecules. In this conformation, it acquires a highly structured array of hydrogen bonding, mimicking the less dense frozen water crystals, which is inherently more viscous. It forms two to eight monolayers of pentagons, around the macromolecules and lipid bilayers of the organelles, nucleus and cell membrane.

The same type of structured water exists around other hydrophobic macromolecules, such as nucleic acids, especially DNA; the membranes of the cell and of the organelles; and around ions, both free ions and those which are found to be associated with proteins, the latter being called counterions. In fact, studies indicate that water is an integral part of the three-dimensional conformation of all macromolecules.[28]

E. Counterions and water

Inside the cells, charged macromolecules such as proteins attract inorganic ions of opposite charge to that of opposite charge to that of the cell's interior. One of the effects of these so-called counterions is to increase osmolarity on the inside of the cell, which means that the concentration of water is greater outside the cell. Thus, water should continuously attempt to move into the cell. However, the condition of non-ideal osmolarity inside the cell counteracts this tendency. When three to eight layers of structured water collect around macromolecules and organelles, we find the condition of non-ideal osmolarity to exist. This structured, or low-density water, does not participate in normal osmotic behavior. The increased concentration of water outside the cell, therefore, does not osmotically move into the cell.[29]

Another effect of counterions is related to the flow of hydrogen ions, or protons, within the cytoplasm. The counterions are attracted to the charged regions of the proteins, supplying an anion where there is a positive charge, and a cation where there is a negative charge on the protein. Fluxes of protons, supplied by the water at the interface between the structured water and the bulk phase water occur not only at the surface of a macromolecular assembly[30] but also along the surface of the lipid bilayers of organelles.[31] Electron transport, in ATP synthesis catalyzed by membranes of mitochondria, is now recognized to also have a protonic nature. Further, flows of cations, especially calcium fluxes, are countered by flows of protons in the reverse direction.[33]

F. Calcium waves

Many investigators have discovered the concentration of calcium ions, [Ca^{++}], inside and outside the cell is variable, progressing through the fluids in veritable waves. [34, 35, 36] Calcium waves outside the cell stimulate calcium waves inside the cell.[37, 38] Various stimuli will create an increased concentration of calcium ions to move through the interior of the cell. *In vitro* experimentation demonstrates that glutamate, ATP, albumen and mechanical stimulation of the cell membrane will all produce a calcium wave.[39, 40] Waves of calcium ions are but one type of oscillation seen inside cells, which, in general, are termed cellular oscillators.

Pischinger recognized, before cellular oscillators were described in the literature, that the extracellular matrix is inherently capable of electromagnetic oscillation.[41] Extracellular as well as intracellular calcium waves have been studied by many investigators. [42,43,44,45,46] Oscillators operating in cell cultures have been discovered which seem to effect fluctuations or calcium ions. These calcium waves seem to be under the control of 1) the concentration of calcium ion, itself, 2) mechanical stimulation from a probe, which here is extrapolated to include the mechanical effects of cell swelling, as well as concentrations of 3) glutamate and 4) albumen. Relationship of calcium waves to the Na^+/K^+ pump has also been demonstrated *in vitro*.[48] Shifts of $[Ca^{++}]$ in the extracelluar fluid are followed by spontaneous oscillations of $[Ca^{++}]$ within the cell, which can be self-perpetuating. These phenomena have yet to be elucidated *in vivo*.[49]

Mechanical stimulation of the cell membrane, however, has been shown to induce calcium waves within that cell and then to be communicated to neighboring cells. This seems to be coupled with dependency upon the presence of glutamate.[50] Long-lasting changes of calcium oscillations, believed to be associated with memory functions in the brain, are associated with glutamate.[51]

G. Fluid waves

To explain the dichotomy presented by the slow movement of macromolecules, e.g. proteins, through the highly viscous cytoplasm[52,53] vs. the rapid metabolic rates of warm-blooded animals, Wheatley postulated two possibilities: one, that ebb and flow movements within the cell, created by overall activity of the cell facilitate the metabolic functions, and two, that there are channels of circulation in the cytoplasm. Abandoning the idea of ebb and flow in favor of the idea of intracellular channels for his study was understandable for Wheatley, as it is for many conventional scientists, since Harvey[54], 350 years earlier had dismissed the prevailing concept at that time of the ebb and flow of fluids with his discovery that blood circulates one-way in the vessels, having been pumped from the heart.[55]

However, Watterson reported in 1987 that clusters of water move through the cell as a wave. He proposed "a new view of the cytoplasm, which he called the wave model of liquid structure. His investigations led him to conclude that large aggregates of molecules of water are shifting, as a wave, and move through the fluid, leaving each individual water molecule relatively in its place. He described the aggregation phenomenon as a pressure wave moving through the fluid, but the individual molecules are relatively stationary. This mimics the activity of water molecules in large bodies of water, such as lakes. Aggregations of water molecules can assume enormous proportions, sometimes containing 1000 molecules in a single cluster. These aggregates can actually take on structural functions in the cell.[56]

Watterson used the term "pressure pixel" to characterize this phenomenon of waves in the cytoplasm. Pressure is exerted on a size scale down to that of a single cluster of water. Below this size, tension between individual molecules prevails. This tension explains the stability of the coordinated movement of the subcellular world, where theories based on the random collisions of thermodynamics break down, in this highly ordered and non-Newtonian environment. It also explains the coherence displayed by the cell in its ability to act as a unit, rather than a collection of independent processes predicted by statistical theories.[57] These concepts as reminiscent of the ideas presented earlier regarding the surface tension of water, in which water naturally creates a sphere. Such a tendency separates water, in this respect, from Newtonian principles of gravity.

H. Membrane channels for water

Membrane channels, specific to the transfer of water between intracellular and extracellular compartments, allow the water molecules to move single file through pores which are classified in the aquaporin family of channels.[58] More recent evidence indicated that water moves through these channels in concentric cylinders, with the dipoles of the water molecules oriented perpendicularly to the normal of the pore's wall.[59]

I. Cytoskeleton and water

The image that is now emerging is that these aggregates of structured water described by Watterson, actually are associated with cytoarchitectural filaments that form a meshwork, the microtrabecular lattice (MTL) which was first reported by Porter 1986.[60] There is still an ongoing debate as to whether these filaments are artifacts of the particular technique of electron microscopy Porter used in which freezing the tissue specimens could produce the appearance of a lattice of filaments by its effect upon the water itself. If these filaments are actually there, however, it is theorized that they interconnect all the elements of the cytoskeleton: the microtubules (MT), the microfilaments (MF) and the intermediate filaments (IF). The MTL are thinner than the MT, MF and the IF, and they are thought to be composed of actin. The MTL forms a web-like mesh which serves, along with the rest of the cytoskeleton, as a scaffolding for the attachment of not only orgartelles, but also macromolecules and whole enzyme systems. Evidence exists that all the enzymes of glycolysis, for instance, are associated on the MTL in tandem, handing off substrates, protons and electrons from one enzyme to the next obviating the need for these elements to return to solution. This chain of enzymes, with respect to their location and their function, has been termed "metabolic channeling," a means by which the cell operates with the greatest physiological efficiency. Likewise, ribosomes, as another example, appear to be organized within the cytoplasm on the MTL, assuring that protein synthesis is securely and conveniently located.[62]

Interestingly, this meshwork of the cytoskleleton is also implicated in other important functions, including hormone signaling and cell volume regulation. With regard to hormones, insulin, epinephrine and glucagon seem to increase the binding of the glycolytic enzymes to the cytoskeleton. These hormones simultaneously stimulate the polymerization of the actin filaments composing the MTL and the MF. Bound enzymes have been shown to be more active than unbound ones *in vitro.*

With regard to cell volume, it is important to be clear that polymerization and depolymerization is a fundamental characteristic of the cytoskeletal system (MT, MF, and IF). Physiological concentrations of calcium will depolymerize the cytoskeleton (CSK)[63, 64, 65] or polymerize it,[66, 67] depending upon its concentration. The CSK system controls several important biological processes including cell shape and motility, growth and secretory processes.[68] Trophic hormones such as ACTH,[69] TSH,[70] FSH,[71] norepinephrine[72] and nerve growth factor (NGF)[73] also modulate cell morphology. Furthermore, increases in cell volume stimulate glycogen synthesis; this cell swelling is thought to be a function of the MTL.[74] Insulin has some of its intracellular effects by inducing swelling of the cell.[75] Of great interest is the control the CSK seems to have over cyclic AMP regulation, since it is a ubiquitous secondary messenger for hormones in many cellular activities.[76] Of course, Ca^{++} is also a ubiquitous secondary messenger for many cellular activities, and further, Ca^{++} is related to the polymerization and depolymerization of the CSK.

Urry, has synthesized a polypeptide segment that mimics elastin, in order to better understand how the subcellular world could explain gross biomechanical movement. He synthesized the sequence valine-proline-glycine-valine-glycine (VPGVG) which repeats itself in the physiological form of elastin. He recognized that applying increasing heat to elastin counter-intuitively increased its order. As temperature went up, the VPGVG polymer actually shortened and could lift a weight. He theorized that the explanation for this phenomenon is in the structure of the water, itself, which is an integral part of the polypeptide. The hydrophobic part of the VPGVG polymer structures the water, which, in turn limits the mobility of the polymer, at least until the temperature raises enough to provide the energy to destructure the water. Then, the polymer can behave according to its tertiary structure and assume its folded shape without the constraint of the structured water. Thereby, the polypeptide converts heat into work. This phenomenon of structured water being destructured by heat could explain many cellular and subcellular mechanisms requiring energy to do work.

Of great interest, is that not only will heat create this effect, but so will any other form of energy, each having its own point at which occurs the transition from structured to destructured water. Of course, we have evidence for all of these forms of energy in the foregoing discussion. Hydrogen ion fluxes provide energy in the form of pH changes and electrical energy flows with the counterion and proton/electron shifts. Calcium ion waves offer changes in chemical gradients, and the water aggregations present pressure and motion characteristics to the system. Thus, the energy of cellular metabolism and influences from outside the cell change the length of the filaments of the cytoskeleton. The lengths of the fibers of the cytoskeleton, it can be postulated, coordinate the conformation changes of the cell. It could also be part of the regulation of cell volume, causing movements of water into and out of the cells.

J. PRM and water

Two European osteopaths, Roques and Gabarel, published a book in 1985, written in French, entitled *Les Fasciae*,[77] in which they proposed a mechanism for primary respiration, which incorporates some of the ideas previously presented into one coherent system. As the title of the book suggests, they approached the topic from the view of the connective tissues. So they looked at the extracellular components of the system, especially including the extracellular matrix. Their model is outlined as follows:

Model of PRM
According to Gabarel & Roques
Ref. *Les Fasciae*, Maloine, 1985

A.) INHALATION PHASE of PRM
1) Expansion of the volume of CSF in the ventricles and subarachnoid space.
2) The Tide is "out" in the extracellular fluids of the body, creating a relative increase in the concentration of electrolytes in the matrix.
3) The increased electrolyte concentration stimulates the secretion of hyaluronidase and other depolymerizing enzymes within the matrix.
4) These enzymes depolymerize the hyaluronic acid backbone and the GAGs of the macromolecules of the matrix.
5) The matrix becomes more fluid and permeable (sol phase).
6) There is a resulting disorganization and relative diminution of the negative charge of the matrix.
7) This relative positive charge attracts anions into the ECF and repels cations, like calcium, from the ECF.
8) MOVEMENT OF WATER AND CATIONS PROCEED INTO THE CELLS FROM THE ECF.
9) Like the macromolecules of the matrix, intercellular fibers become depolymerized and more mobile, permitting the opening of the fenestrations between the lymphatic endothelial cells, which line the lymphatic vessels.
10) MOVEMENT OF WATER, METABOLITES AND PROTEINS PROCEED INTO THE LYMPHATIC SYSTEM.

B.) EXHALATION PHASE of PRM
1) Flushing of CSF from the ventricles and subarachnoid space creates a tide. The Tide is "in," in the ECF.
2) This dilutional effect decreases the electrolyte concentration in the matrix.
3) The secretion of hyaluronidase and other enzymes is consequently reduced.
4) Repolymerization of and binding of water to the PG/GAGs ensues.
5) The matrix becomes more stable and less fluid amd permeable (gel phase).
6) Negative charge becomes a well-organized, static

field in the matrix.

7) Cations are attracted to the ECF.
8) There is a firming of the endothelial cell connections of lymphatics.
9) Proteins remain in the ECF and lymph fluids.
10) Osmotic forces pull water into the ECF.
11) WATER AND DISSOLVED SUBSTANCES LEAVE THE CELLS.

An advancement of the model from Gabarel and Roques to include the intracellular environment is postulated next:

MODEL OF THE PRM

As it exists generally in the intracellular space

A.) INHALATION PHASE of PRM
1) MOVEMENT OF WATER AND CATIONS (Ca^{2+}) INTO THE CELLS FROM THE ECF.
2) Calcium wave and fluid wave is transmitted across the cell.
3) Cell volume is momentarily increased.
4) Polymerization of cytoskeleton occurs.
5) Cellular enzymes are activated.
6) Production of ATP and proteins is increased.

B.) EXHALATION PHASE of PRM
1) MOVEMENT OF WATER AND CATIONS (Ca^{2+}) OUT OF THE CELL INTO THE ECF.
2) Cell volume is momentarily decreased.
3) Depolymerization of cytoskeleton occurs.
4) Cellular machinery is momentarily deactivated. ▲

REFERENCES

[1] Still AT, *Osteopathy, Research and Practice*, Eastland Press, 1992, paragraph 909, p. 279.
[2] Still, AT, *Philosophy of Osteopathy*, Published by the author, 1899, Republished by American Academy of Osteopathy, fifth reprint, 1977,pp. 149-150.
[3] Still, AT, *Philosophy of Osteopathy*, American Academy of Osteopathy, p. 39.
[4] Still, AT, *Philosophy of Osteopathy*, American Academy of Osteopathy, p. 109.
[5] Still, AT, *Philosophy of Osteopathy*, American Academy of Osteopathy, p. 104.
[6] Still, AT, *Philosophy of Osteopathy*, American Academy of Osteopathy, p. 104.
[7] Still, AT, *Philosophy of Osteopathy*, American Academy of Osteopathy, p. 105.
[8] Still, AT, *Philosophy of Osteopathy*, Republished by AAO.
[9] Still, AT, *Philosophy of Osteopathy*, American Academy of Osteopathy, p. 260.
[10] Water, *The World Book Encyclopedia*, 1999, vol. 21, p. 116.
[11] Schwenk, T, *Sensitive Chaos*, The creation of flowing forms in water and air, Rudolf Steiner Press, London, reprinted 1999.
[12] Schwenk, T, *Sensitive Chaos*, p. 75.
[13] Schwenk, T, *Sensitive Chaos*, p. 31-33.
[14] Water, *The World Book Encyclopedia*, 1999, vol. 21, p. 117.
[15] Water, *The World Book Encyclopedia*, 1999, vol. 21, p. 120.
[16] Water, *Encyclopedia Americana*, 1993, vol. 28, p. 432.
[17] Water, *Encyclopedia Americana*, 1993, vol. 28, p. 433.
[18] Good, W, Water relations of altered body functions, Medical Hypothesis 7:85-110, 1981.
[19] Water, *The World Book Encyclopedia*, 1999, vol. 21, p. 122.
[20] Cameron, IL, Kanal, KM, Keener, CR and Fullerton, GD, A mechanistic view of the non-ideal osmotic and motional behavior of intracellular water, Cell Biol Int 21: 99-113, 1997.
[21] Luby-Phelps, K, CytoarchitectLure and physical properties of cytoplasm: volume, viscosity, diffusion, intracellular surface area [Review], Int Rev Cytol 192:289-221, 2000.
[22] Sherrington, C, 'Man on his nature,' Gifford Lectures 1937/8. Penguin Books, Harmondsworth, Middlesex, pp. 69-98, 1940.
[23] Schwenk, T, *Sensitive Chaos* p. 58.
[24] Wiggins, PM, high and low density water and resting, active, and transformed cells, Cell Biol Int 20:429-435, 1996.
[25] Water, *The World Book Encyclopedia*, 1999, vol.2 1, P. 122.
[26] Saenger, W, Structure and dynamics of water surrounding biomolecules, Ann Rev Biophys, Biophys Chem, 16:93-114, 1987.
[27] Young, MA, Ravishanker, G, and Beveridge, DL, A 5-nanosecond molecular dynamics trajectory for B-DNA: Analysis of structure, motions, and solvation, Biophys J 73:2313-2336, 1997.
[28] Zhang, L, Hermans, J, Hydrophilicity of cavities in proteins, Proteins 24:433-438, 1996.
[29] Good, W, Medical Hypothesis 7:85-110, 1981.
[30] Deshmukh, VD, Cascading morphoregulatory energy and the biological form: thoery and reality, Medical Hypothesis 35:59-67, 1991.
[31] Teissie, J, Prats, M, Soucaille, P, and Tocanne, JF, Evidence for conduction of protons along the interface between water and a polar lipid monolayer, Proc Natl Acad Sci USA 82:3217-3221, 1985.
[32] Teissie et al, Proc Natl Acad Sci USA 82: 3217-3221, 1985.
[33] Zhang, L and Hermans, J Proteins 24:433-38,1996.
[34] Berridge and Rapp, A comparative survey of the function, mechanism, and control of cellular oscillators, J Exp Biol 81:217-279, 1979.
[35] Nadal, Fuente, Pastor, McNaughton, Plasma albumen induces calcium waves in rat cortical astrocytes, GLIA 19:343-51, 1997.
[36] Strumwasser and Vogel, Cellular oscillators and biologic timing: The role of proteins and Ca2+, Prog Brain Res vol 92, ed. Jnosse, Buiss, Tilders, 1991.
[37] Hassinger, Guthrie, Akinson, Bennett, Kater, An extracellular signaling component in propogation of astrocyte calcium waves, Neurobiol, Proc Natl Acad Sci USA 93:13268-13273, 1996
[38] Zanotti, Charles, Extracellular calcium sensing by glial cells: Low extracellular calcium induces intracellular calcium release and intercellular signaling, J Neurochem 69:1997.
[39] Reetz, Weisinger, Reiser, ATP-induced oscillations of cytosolic Ca2+ activity in cultured astrocytes from rat brain are modulated by medium osmolarity indicating a control of [Ca2+] oscillations by cell volume, Neurochemical Research 22:621-628,1997.
[40] Charles, Merrill, Sanderson, Intercellular signaling in glial cells: Calcium waves and oscillations in response to mechanical stimulation and glutamate, Neuron 6:983-992, 1991.
[41] Pischinger, A, *Matrix and Matrix Regulation* Heine, H (ed.) Brussels: Haug Int, 1991.
[42] Strumwasser and Vogel, Cellular oscillators and biological timing: The role of proteins and Ca2+, Progress in brain research, vol. 92, Ed. Jnosse, Buiss, Tilders, 1991.
[43] Reetz, Weisinger, Reiser, ATP-induced oscillations of cytosolic Ca2+ activity in cultured astrocytes from rat brain are modulated by medium osmolarity indicating acontrol of [Ca2+] oscillations by cell volume, ATP-induced [Ca2+] oscillations in astrocytes, Neurochemical research, vol. 22, no. 5, 1997, pp.621-8.
[44] Nadal, Fuente, Pastor, McNaughton, Plasma albumen induces calcium waves in rat cortical astrocytes, GLIA (1997) 19:343-51.
[45] Hassinger, Guthrie, Atkinson, Bennett, Kater, An extracellular signaling component in propagation of astrocyte calcium waves, Neurobiology, Proc Natl Acad Sci USA (1996), vol. 93, pp. 13268-13273.
[46] Zanotti, Charles, Extracellular calcium sensing by glial cells: Low extracellular calcium induces intracellular calcium release and intercellular signaling, J Neurochemistry, vol. 69, no 2, 1997.
[47] Berridge, Rapp, A comparative survey of the function, mechanism and control of cellular oscillators, J Exp Biol (1979), 81:217-279.
[48] Golovina, Bambrick, Yarowsky, Krueger, Blaustein, Modulation of two functionally distinct Ca2+ stores in astrocytes: Role of the plasmalemmal Na/Ca exchanger, Ca2+ regulation in astrocytes, GLIA (1996) 16:296-305.
[49] Schrode, Klein, O'Neil, Putnam, Shrinkage-induced activation of Na+/H+ exchange in primary rat astrocytes: role of myosin light-chain kinase, Am J Physiol, 269 (Cell physiol 38): C257-C266, 1995.
[50] Charles, Merril, Sanderson, Intercellular signaling in glial cells: Calcium waves and oscillations in response to mechanical stimulation and glutamate, Intercellullar Ca2+ signaling in glial cells, Neuron, vol. 6, 983-992, June 1991.
[51] Paste, Pozzan, Carmignoto, Long-lasting changes of calcium oscillators in astrocytes, a new form of glutamate-mediated plasticity, Long-term changes in astrocyte response to glutamate, J Biol Chem, vol. 270, no. 25, June 23, 1995, pp. 15203-15210.

[52] Hazelwood, CF, Rorschach, HE and Lin, C Diffusion of water in tissues and MRI, Magnetic Resonance in Medicine 19:214-216, 1991.
[53] Good, W Meical Hypothesis 7:85-110, 1981.
[54] Harvey, W, *'De Motu Cordis,' (Movement of the heart and blood in animals. Translated from the Latin)*, Blackwell, Oxford 1957.
[55] Wheatley, DN, Mini-review on the possible importance of intracellular circulation, Life Sciences 36:299-307, Pergamon, 1985.
[56] Watterson, JG, A role for water in cell structure, Biochem J, 248:615-617, 1987.
[57] Wattefson, JG, The pressure pixel - unit of life?, Biosystems 41:141-152,1997.
[58] Engel A, Walz, T, and Agre, P, The aquaporin family of membrane water channels, Current Opinion in Structural Biology 4:545-553, 1994.
[59] Sansom, MSP, Kerr, ID, Breed, J, and Sankararamakrishnan, R, Water in channel-like cavities: Structure and dynamics, Biophys J, 70:93-702, 1996
[60] Porter, KR, In 'Organization of Cell Metabolism' (GR Welch and JS Clegg, eds.) pp. 9-26. Plenum, NY, 1986.
[61] Kondo, H, On the real structure of the cytoplasm matrix: learning from the embedment-free electron microscopy [Review], Arch Histol Çytol 58(4):397-415, 1995.
[62] Clegg, JS, Cellular infrastructure and metabolic organization, Current Topics in Cellular Regulation 33:3-147, 1992.
[63] Weisenberg, RC, Microtubule formation in vitro in solutions containing low calcium concentrations, Science 177:1104, 1972.
[64] Dancker, P, Low, I, Dual effect of Ca2+ on ultrasonic ATPase activity and polymerization of muscle actin, Biochem Biophys Acta 484:169, 1977.
[65] Marcun, JM, Dedman, JR, Brinkley, BR, Means, AR, Control of microtubule assembly-disassembly by calcium dependent regulatory protein, Proc Natl Acad Sci USA 75:3771, 1978.
[66] Foskett, JK, and Spring, KR, Involvement of calcium and cytoskeleton in gallbladder epithelium cell volume regulation, Am J Physiol 248 (Cell Physiol 17): C27-C36,1985.
[67] Nanua, C, and Masters, C, The influence of calcium. ions on the adsorption of glycolytic enzymes to cellular structure, Biochem Int 15:835-842, 1987.
[68] Dustin, P, Microtubules, Springer-Verlag, New York, p. 440, 1978.
[69] Ramachandran, J, Suyama, AT, Inhibition of replication of normal adrenocortical cells in culture by adrenocorticotropin, Proc Natl Acad Sci USA 72:113, 1975.
[70] Avivi, A, On the mechanism of TSH-induced formation of follicle-like structures in cultured thyroid cells, Cell Biol Int Rep, 1982.
[71] Hutson, JC. Garner, CW, Stocco, DM, Effects of serum components on the morphology of Sertoli cells in culture, Anat Rev 197: 205, 1980.
[72] Balter, NJ, Cowden, MW, Schwartz, SL, Induction of membrane alterations by norepinephrine: studies with macrophages and phospholipid monolayers, J Pharm Exp Therap 201:627, 1977.
[73] Schubert D, LaCorbiere, M, Whitlock, C, Stallcup, W, Alterations in the surface properties of cells responsive to nerve growth factor, Nature 273:718, 1978.
[74] Al-Habori, M, Microcompartrnentation, metabolic channeling, and carbohydrate metabolism, Int J Biochem Cell Biol 27:123-132, 1995.
[75] Al-Horabi, M, Mechanism of insulin action, role of ions and the cytoskeleton, Int J Biochem 25:1087-1099, 1993.
[76] Zor, U, Role of cytoskeletal organization in the regulation of adenylate cyclase-cyclic adenosine monophosphate by hormones, Endocrine Rev 4:1-21, 1983.
[77] Gabarel, B, Roques, M, *Les Fasciae*, Maloine, Paris, 1985.

Owen's Law of Tissue Fluid Hydrodynamics

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When a body is subject to surrounding pressure change, either fluid or air, there is a tendency for a shift of mobile systemic fluids. The direction of shift is towards the periphery (upper and lower extremities) when the ambient pressure is reduced, and visa versa when the pressure increases (towards the head and trunk).

Theory Definition: A sphere can be defined as that shape where its volume has the least possible amount of surface area of its surface.

The phenomenon occurs principally due to the volume to surface area ratio of various body parts. In the arms and legs for example, being sausage-shaped, the ratio is very different to that of the skull, being almost spherical. Where the volume/surface ratio is low, it implies there is less fluid for a large surface area, thereby making that fluid more responsive to surface area pressure changes. Increasing the surrounding pressure (as in the case when SCUBA diving) will have the effect of causing moveable fluids to shift from the arms and legs to more central areas of the body where there is less surface area to more volume, i.e. the head and trunk. Decreasing the surrounding pressure however (as in the case when flying at altitude) will have the reverse effect and fluids will be moved into the arms and legs.

Applications and Considerations

Theoretically it would be true to say that each time there is a barometric change in our air pressure it would produce a fluid shift in our body. Albeit only small, it may account for why some people can sense a change of weather 'in their bones'! Possibly of more significance, and to a much greater extent, this phenomenon takes place in number other situations including:

When SCUBA diving

Recent experiments show that when comparing the circumferences of a diver's thigh, calf and skull first at sea level and then at 60 feet below the surface after 30 minutes, there was an increase in the circumference of skull by up to 1cm. Correspondingly the circumference measurements of the thighs and calves had reduced by 1cm and 0.5cm respectively. It would be interesting to receive comments from medical diving specialists as to whether they feel this phenomenon could influence nitrogen narcosis precipitation.

High altitude air travel

Many modern aircraft are pressurized to 6,000 feet. I am told that it is not possible to pressurize an aircraft any lower than that because the weight and width of materials needed to stop the aircraft from exploding would make it too heavy to fly. As a result, as the aircraft ascends the cabin pressure drops and stays at a predetermined pressure of 6,000 feet. This drop in cabin pressure exerts a different effect on the different areas of the body resulting in a movement of vascular and perivascular fluids towards the periphery, i.e. the arms and legs. Passengers commonly note a feeling of swelling in their ankles and fingers and are advised by airlines to undergo some simple exercises to try and stimulate the circulation to try to cope with the increased demands suddenly imposed on it. As a result of the fluid movement towards the periphery, there is a relative stasis in the afferent peripheral fluids and clot formation is predisposed to. Perhaps future consideration to this phenomenon may place less emphasis on passenger inactivity and more on the increase in fluid pooling in the lower extremity as a cause of the much talked about thrombus formation following air travel.