Fluid Hydraulics in Human Physiology

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The principles of fluid hydraulics are an essential part of virtually every area of human physiology. Fluid movement is necessary for fluid balance, delivery of leukocytes and red blood cells, movement of lymphatic fluid, venous flow, delivery of glucose, neurotransmitters, hormones, and enzymes, as well as movement of all electrolytes through and across cell membranes. This continuous movement of essential substances depends largely upon fluid hydraulics for both intracellular and extracellular fluid exchange. It is the continuous hydrodynamic fluctuation of waves of fluid that provides the continuous delivery of oxygen rich RBCs, nutrients, and the many necessary substances to the cell membranes that maintains cellular health and integrity. Cellular metabolism depends on the continuous availability of an abundance of oxygen and various nutrients. Also, waste products of metabolism must be continuously washed away to avoid stagnation by the buildup of HC03, lactic acid and other metabolic breakdown products. It is fluid hydraulics that delivers the essential nutrients so that this cellular metabolic exchange can take place in every cell throughout the body.

The arteries and veins deliver a large percentage of the blood flow into the general vicinity of the cells. Like expressways deliver traffic to the communities and the smaller highways deliver cars deeper into the neighborhoods. In some neighborhoods, there are no roads in between the houses. A similar situation is true of our circulatory system. Large arteries and smaller arteries deliver blood into the general area throughout the body. Similar to our neighborhoods, there are no vessels in the extreme periphery. Therefore, it is logical to hypothesize that it is this hydraulic fluctuation of vital fluids that actually delivers extracellular fluids to and across fascial planes, around cellular barriers, into and out of bursae and synovial spaces, and across cell membranes into the most remote cells.

Guyton and Hall[1] state that 20 percent of the body weight is in the extracellular compartment, about 14 liters of fluid. This fluid moves in between the cells, around, across cellular barriers, and fascial planes to wherever it is needed. The fluids move where there are neither vessels nor natural passageways. It is my hypothesis that it is this continuous hydraulic pressure fluctuation that is the driving force that moves this large, vital fluid volume.

Editor's note: This article from the archives has been formatted to comply with The AAO Journal's style guidelines, but original language, spelling and punctuation have been retained per its original publication in the Summer 1997 issue of the *AAOJ*.

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With a discussion of the physics of hydraulics, one must consider pressure as a factor. Pressure of a fluid at rest is defined as force per unit area, with the force being understood to be perpendicular to the area. Therefore, the formula that applies is (P) pressure = (F) force divided by (A) area. $P = F/A$.[2]

If a column of fluid is in the vertical position, as is the usual case for humans, the pressure exerted is calculated by multiplying the height of the column x the density (d) x the constant for the fluid(g). Therefore, $P = hdg$. The total weight of a column at rest is calculated as: $W = Ahdg$. With fluids in motion, Bernoulli's equation applies taking into consideration streamline flow and turbulent flow which considers eddie currents, whirlpool effect, and friction drag.

Pascal's Principle states that a "Change of pressure exerted at any point in a confined fluid is transmitted undiminished in all directions to all points in the fluid."[2] The human body consists of many closed fluid systems that respond exactly as Pascal's Principle states when pressure is applied. So, when one places a finger with the subtlest pressure on a closed container (the body) filled with non-compressible fluid, that force is transmitted instantly to all areas of the body and in all directions, equally. This gives explanation to the far-reaching effect of the healing touch. This further explains why merely placing a hand on a person can facilitate changes.

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A practical demonstration of Pascal's Principle is with two examiners palpating the same patient. One examiner is palpating the supraclavicular space (Sibson's fascia) while the other is palpating the urogenital diaphragm. When one examiner places a light pressure on the urogenital diaphragm, the other examiner immediately feels the pressure transmitted to the opposite Sibson's facia, and vice versa. Clearly demonstrating the instant transmission of the hydraulic pressure wave to all areas equally and instantly.

Another demonstration to illustrate the power of the touch is the "V Spread."[3] With the "V Spread," Pascal's Principle is utilized to direct and focus a fluid force vector within the cranium directly onto the exact point along a suture which is found to be restricted. This gentle continuous force is held on that point until there is a release and free motion restored. In fact, all "functional" types of osteopathic manipulative treatments utilize the principles of fluid hydraulics in one method or another to make finesse corrections of somatic dysfunction.

Ligamentous Articular Strains (LAS) methods, as taught by A. T. Still and William Garner Sutherland, DO,[4] use the principles of hydraulics by utilizing the Cranial Rhythmic Impulse (CRI) as a correcting force.

LAS treatments Sutherland[4] taught to correct a restriction by:

1. Disengagement (by either compression or decompression)
2. Exaggeration (with finesse), and
3. Balancing directly on the point of restriction to facilitate a release. This is another practical demonstration of Pascal's law.

With hydraulics, an object weighing very little can exert a tremendous pressure if the force acts only on a small surface area. On the other hand, the weight, such as atmospheric air in space whose weight is 5.7 x 10 tons, creates only a relatively small pressure on the earth since the force is spread out over the entire surface of the globe. (1 Atmosphere= 14.7 lb./sq. in.)

Other examples of industrial application of Pascal's Principles are: the hydraulic lift; the hydraulic jack; the hydraulic press which are widely used in industry to bale cotton, cardboard, rags, and etc.; on flood gates; in milling; turning machines; drilling; cranes and hoists; truck lifts; industrial shears; milling; automobile transmissions; and anywhere great force is required.[5,6]

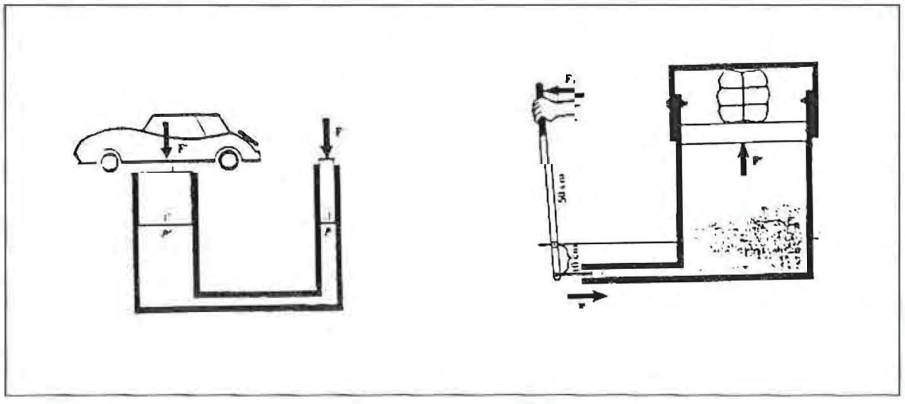
The two figures below illustrate examples of how a small force (F) applied to a small piston in a closed system which contains a non-compressible fluid is able to create a far greater lifting force (F-1).

There is a directly proportionate relationship between the force and area of the pistons illustrated. Thus:[1]

$$\frac{F\text{-}1}{A\text{-}I} = \frac{F\text{-}2}{A\text{-}2}$$

The circulation of arterial blood, venous blood, lymphatic fluid, the axoplasmic flow, and cerebrospinal fluid movements are directly affected by the principles of hydraulics. The neurovascular compartments and other fluid reservoirs of the body are contained by membranous fibroelastic membrane. Because of the high fluid content of the body, structures respond to every pressure fluctuation. Every vibration, pulsation, or muscular contraction compresses the fluid within the adjacent neurovascular bundle. Not only does the rebound of the elastic stretch of the fascia propel fluids, but also the forces produced by the vibrations and pressure fluctuate against the flexible yet resistant boundaries that send hydraulic fluid waves through their one-way valves. These vibrations provide a continuous flow of fluid along the vessel pathways.

Only the arterial system has its own pumping mechanism, the heart. Not only does the heart propel arterial blood through the arteries, but the vibrations produced by the heart contractions send hydraulic waves through all the adjacent structures as well. The resulting hydrostatic waves are sent out like the ripples radiating out from a pebble thrown into the middle of a smooth pond. Pressure waves are projected outwardly, throughout the body. These pulsation, vibrations, and pressure waves of fluid hydraulics are continuously radiating outwardly, continuously moving essential fluids into all areas of the body.



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CRI or "The Primary Respiratory Mechanism,"[3] is a beautiful example of how subtle pressure fluctuations and waves of hydraulic pressure contribute to the process of cellular health.

The circulation of Cerebro-Spinal Fluid (CSF) flows from its point of origin, in the choroid plexuses in the ventricles, around and through the brain and down the spinal cord. The CNS has an inherent motility (CRI) of both the brain and spinal cord that produce rhythmic waves of the CSF fluid movement. The CSF moves not only down the spinal cord but also down the axons, contributing to the transneuronal axoplasmic flow. "Every organ in the body exhibits the phenomenon of pulsation or rhythmic action[1] which is incessantly active, dynamic, highly mobile, able to move fluid forward, backwards, sideways, circumduct and to rotate."[7] "Four definite motions have been observed at operation."[8] These motions propel the extracellular fluids into and across semipermeable membranes and deliver nutrients and remove the metabolic waste products even from synovial spaces, bursae, and other non-vascular compartments. Every cell membrane of the body is continuously and rhythmically bathed with these essential fluids in a fashion similar to the ebb and flow of ocean as the waves roll up onto the beach and then recede back into the ocean, again and again rhythmically 24 hr/day. These waves of fluid fluctuation are constantly bathing the cells in every part of the body, equally.

Of the four motions of cerebral movements reported,[1] one is synchronous with the cardiac contractions, another coincides with respiration, and one is unrelated to either the cardiac or respiratory motion. The last is an undulating pulsation which is much slower and unrelated to the other three. Harold Magoun, Sr. postulated that the inherent pulsatile motion of the CNS has its origin in embryologic development and sustained this movement of coiling and uncoiling rhythmic motion pattern of the CNS.

Harold Magoun, Sr. did a masterful job of describing the circulation and the hydrodynamic action of the CSF.[3] He further discussed the nerves as "hollow tubes" and the free circulation in the perivascular and perineural spaces that communicate freely with the subarachnoid spaces. The inherent motility of the CNS would provide a dynamic fluctuating force (CRI) for circulation of CSF. The underlying driving mechanism of this movement remains unexplained to this date.

The osteopathic physician skilled in palpation can readily feel the CRI in every structure of the body. By evaluating the CRI for its strength, rhythm, amplitude, and timing, one gets the general idea of the general physical and mental state of health of the individual at that moment. Alterations of normal motion can be identified by the attentive physician.

Fluid transport across the semipermeable cell membrane depends on a variety of factors, other than just the hydrodynamic pressure mechanism. Various factors affect the net rate of diffusion through the cell membrane. Several of those to be considered are:[3]

1. The Osmolar gradient of various anions and cations.
2. The electrical potential of particles on both sides of the cell wall.
3. Integrity and porosity of the semipermeable cellular membrane.
4. Hydrostatic pressure gradient at the cell membrane.
5. The abundance of available fluids bathing the cell wall.
6. Lipid solubility
7. Thickness of the membrane
8. Number of protein channels through which the substances can pass.
9. Temperature
10. Molecular weight of the diffusing material

Various forces that act on the fluids confined in within the neurovascular compartments, muscle bundles, and other tissues compartments of the body. All these forces conform in accordance to Pascal's Principles. A few of these forces are:

1. Force of adjacent muscle contractions
2. Competency of the one-way valves in the veins
3. Condition of one-way valves in the lymphatic vessels
4. Rebound of the fibroelastic sheath of the neuro vascular bundle
5. Effects of the "8 diaphragms" of the body[1]
6. Quality and strength of the CRI
7. Electromagnetic vibratory rate of the tissue
8. Somatic Dysfunction of the contiguous structures
9. Vibrations produced by the cardiac systole and diastole
10. Vibrations produced by arterial pulsations
11. Pressure fluctuation due to pumping action of the respiratory diaphragm
12. Daily physical activities
13. Elevation and dependency of various parts of the body
14. Normal gravitational force...14.7 lb/sq. in.

All of the above forces are continuously producing hydraulic pressure fluctuations on the body parts that contribute to dynamic pressure changes and fluid movement throughout the body. It is

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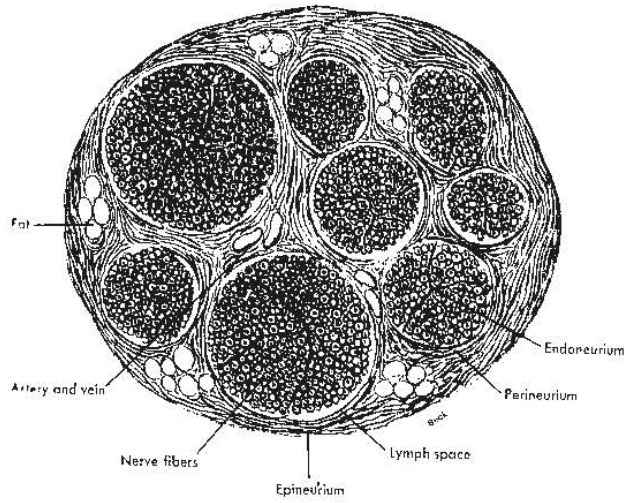
easy to understand how fluids continue to flow on a day-in and day-out basis.

The CRI is the subtlest, most consistent, and most overlooked energy force acting on the closed fluid compartments of the body. The CRI is "the Primary Respiratory Mechanism"[9] or life's force. The CRI ceases at the moment of death. On two occasions, I have been privileged to have been palpating the cranium at the moment of death and witnessed the cessation of the CRI. Life was definitely gone at that very instant.



Peripheral nerve

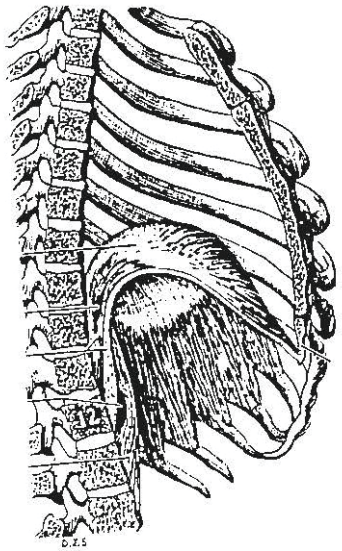
Water weight in the human body is stated to be 60 percent of the total body weight or 42 liters of fluid.[3] Twenty-eight liters are intra cellular...thus 40 percent of body weight. The extracellular fluids comprise 20 percent of the body weight or 14 liters. Blood volume makes up 8 percent or 5 liters. When we consider that blood is noncompressible, one can better appreciate how every fluid wave radiates throughout the entire body millions of times each day. Pascal's Principle of hydraulics is working all day, every day.

Transneuronal axoplasmic flow of the neuroproteins and viscous axoplasm occurs in at least two rates along the axons. The flow occurs down through the many layers of the axons, around the neurofibrils within the neural membranes encasing the axons.[1] This illustration demonstrates the complex, multilayered nature of the axon itself.

The neuropeptides are synthesized as an integral part of large-protein molecules by the ribosomes in the neuronal cell body. The protein molecules then enter the endoplasmic reticulum of the cell body and subsequently the Golgi apparatus, where two changes occur: First, the protein is enzymatically split into smaller fragments and thereby releases either the neuropeptide itself or a precursor of it. Second, the Golgi apparatus packages the neuropeptide into minute transmitter vesicles that are released into the cytoplasm. Then the transmitter vesicles are transported all the way to the tip of the nerve fiber by axonal streaming of the axon cytoplasm, traveling at the slow rate of only a few centimeters per day.

"These vesicles release their transmitter in response to action potential."[10] These neuronal proteins are thought to have both morphogenic influence, as well as, genetic expression and regeneration of nerve to muscle transmission. Omer and Spinner[10] state that these axonally transported materials may have a "yet unknown trophic factor." The health and function of the organ tissue depend upon a regular and abundant supply of these neuronal proteins for its health and function. As A.T. Still stated, "Cerebrospinal fluid is one of the highest known elements that is contained 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 field irrigated at once or the harvest of health be forever lost."[11]

Guyton seems to be partially validating Dr. Still's sage statement. The dynamic effects of the respiratory diaphragm are keystone to fluid movement and, therefore, should always be considered in any discussion of fluid movement. During inhalation, the diaphragm flattens as the thoracic cage expands, sucking air into the lungs and creating an increase in the intrathoracic and intraabdominal pressure. During inhalation, venous return comes to a virtual standstill and causes temporary congestion of the head, neck, abdomen and extremities. This increase in pressure on the mediastinum and the sympathetic



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plexus, results in an increase sympathetic tone and the resulting physiologic effects.

A proposed model or paradigm to demonstrate hydraulics of the human body would be a longitudinal fluid filled structure with longitudinal interconnecting compartments with eight one-way lateral baffles. The material of the container and compartments are made of tough, flexible, and nonelastic material. Fluid is able to fluctuate freely with every vibration or pressure change from one end to the other as long as all the baffles are free to move. If one were to visualize that any one of these eight baffles were to become stuck, it is easy to see that the free flow and fluctuation of fluids would be seriously reduced. A restricted baffle becomes a "choke point" that interrupts the free fluid movement. The same restriction occurs in the body when one of our eight diaphragms becomes impaired.

Using the preceding as our model, the anatomic diaphragms represent "choke points" for fluid movement. In the human body, these anatomic fluid "choke points" are listed as follows: (from the ground up)

1. Plantar fascia;
2. Popliteal fascia;
3. Urogenital diaphragm;
4. Respiratory diaphragm;
5. Thoracic inlet;
6. Occipito-Atlantal fascia;
7. Cerebellar tentorium; and
8. Diaphragma sellae (Sella Tentorium).

Any somatic dysfunction of these "diaphragms" or "choke points" can substantially impede healthy lymphatic and venous circulation.

A restriction of the normal physiologic motion due to somatic dysfunction of any one of these diaphragms will interrupt free fluid fluctuation throughout the body. For one to enjoy a full measure of health, all of his diaphragms must be moving freely for free fluid exchange throughout the entire body. Whenever physiology is interrupted in this manner, the opportunity for disease to begin is present.

With the consideration of the principles of hydraulics, it becomes clear what a broad range of effects these principles have in human physiology. This understanding is especially useful to those of us who study and apply osteopathic treatment utilizing craniosacral and other functional treatment methods. It is through these principles that we are able to project and focus fluid forces and feel when balanced membranous tension is achieved and when the release occurs. With the slightest touch, the pressure at all points in the body is increased proportionately. It is no wonder that we are continuously amazed by the potency of this type of finesse treatment.

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Below are the answers to *The AAO Journal's* September 2020 quiz on the article titled, "The Immediate, Intermediate, and Long-Term Effects of Osteopathic Manipulative Treatment on Pulmonary Function in Adults with Asthma," by Kody M. Kasten, OMS IV; Samantha K. Tyler, OMS IV; Anna R. Johnson, OMS IV; Erika R. Kolakowski, OMS IV; Jonathan Pickos, OMS V; Katherine Heineman, DO; Chunfa Jie, PhD.

1. **c.** Remove restrictions affecting the vagus nerve as it exits the skull to balance parasympathetic tone.
2. **b.** The data suggest that using OMT on adult asthmatics may significantly improve a patient's tolerance for activity, reactions to environmental stimuli, symptoms, and emotional function.
3. **d.** The AQLQ(S) had three separate domains including Symptoms, Activity Limitations, and Emotional Function.
4. **c.** After completion of the treatment protocol, participants were screened for somatic dysfunction resolution by a board-certified OMM/NMM physician and retreatments were provided if inadequate resolution was found.