

L. W. SUROFF
ULTRASONIC METHOD AND APPARATUS FOR PUMPING
FLUIDS THROUGH A HUMAN

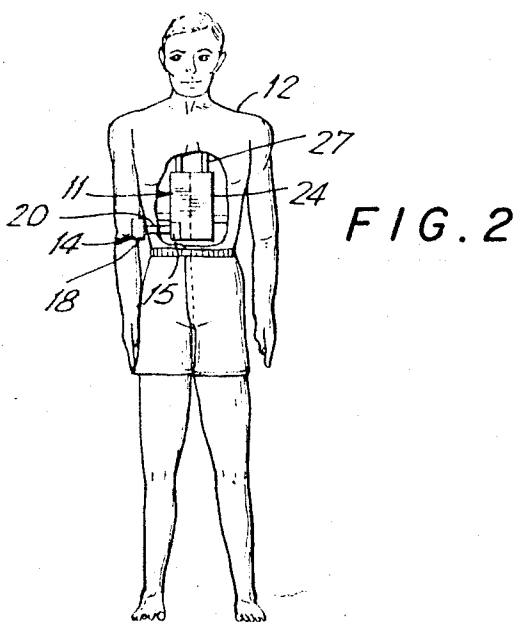
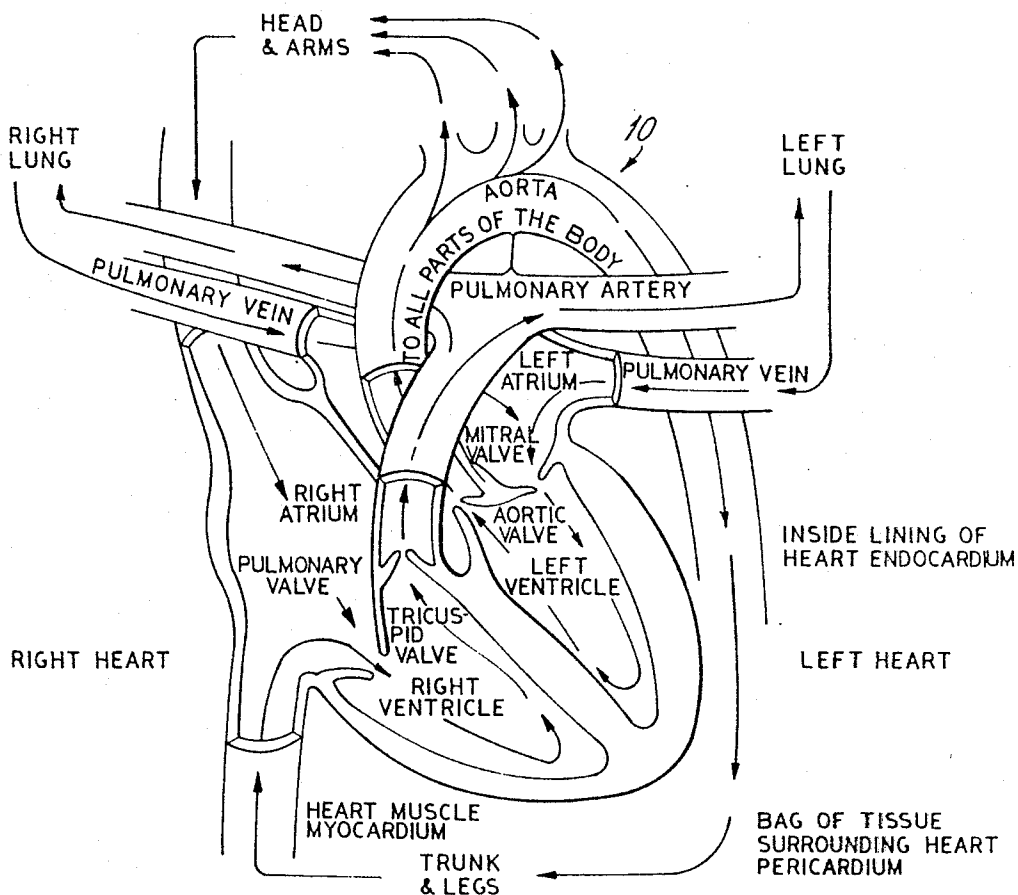
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Sheet 1

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FIG. 1



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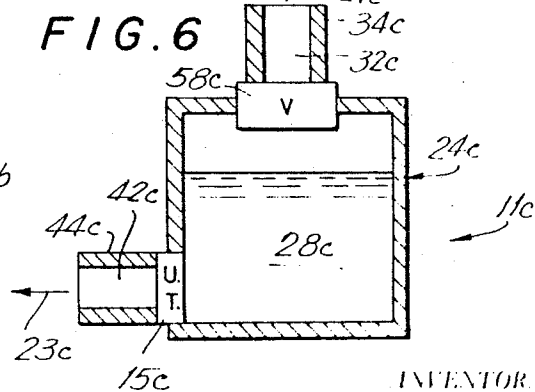
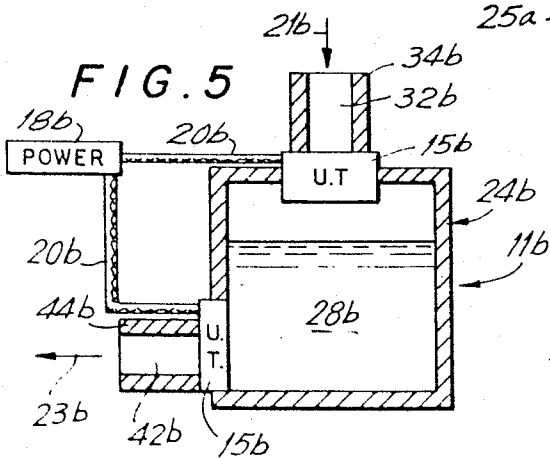
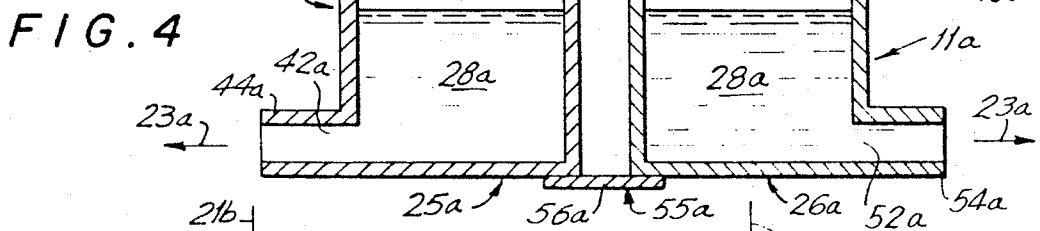
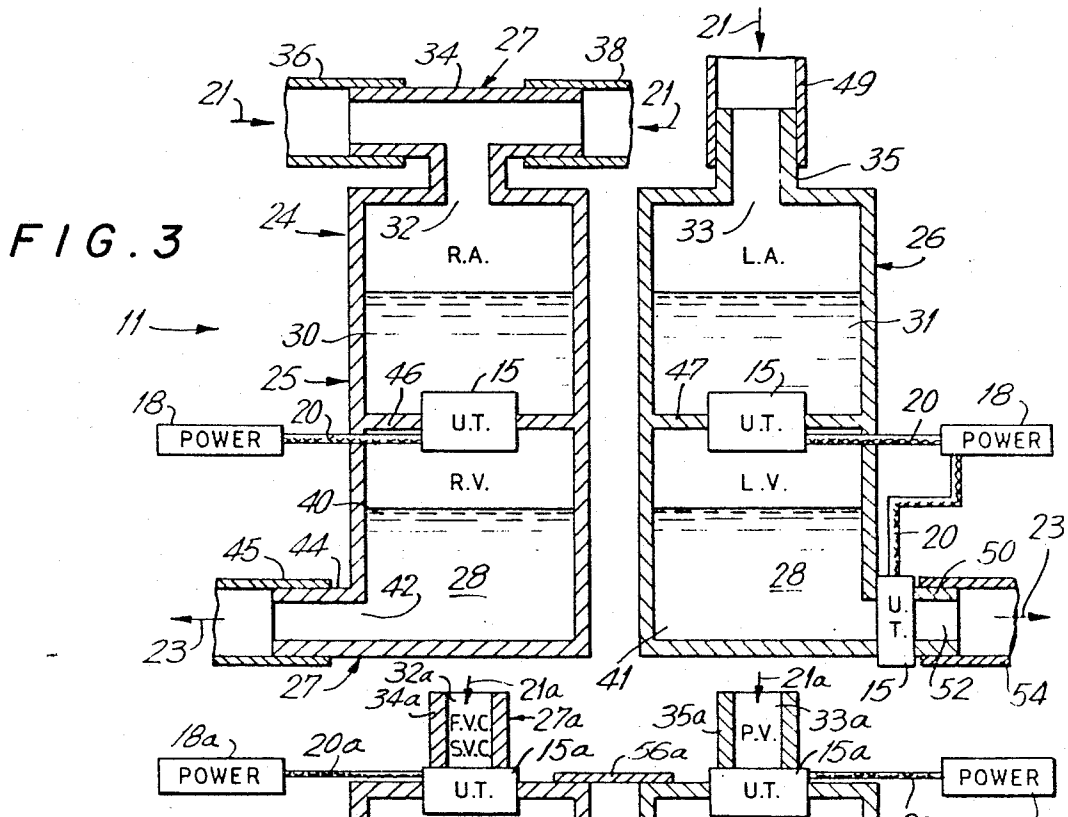
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FIG. 7

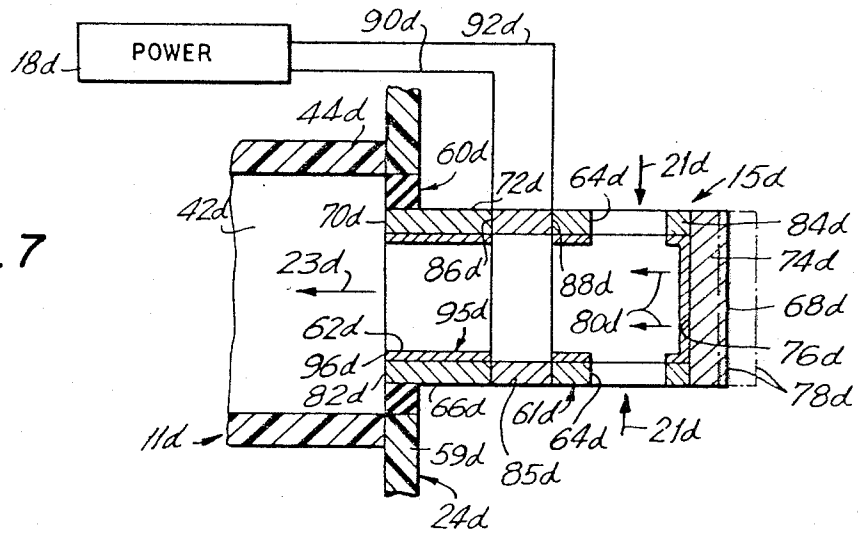


FIG. 8

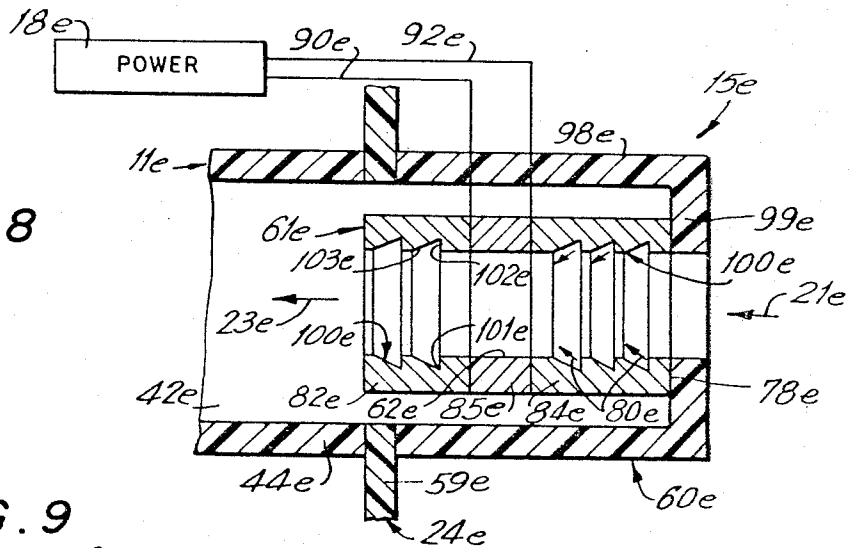
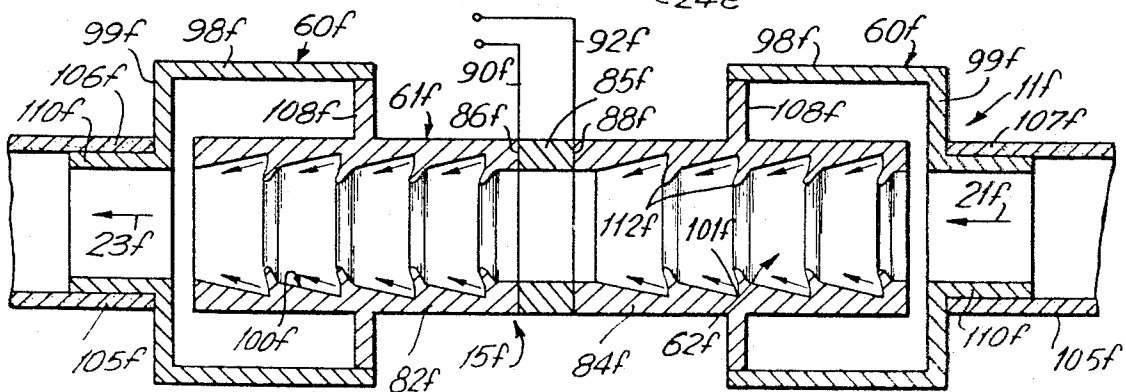


FIG. 9



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ULTRASONIC METHOD AND APPARATUS FOR PUMPING FLUIDS THROUGH A HUMAN

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28 Claims

ABSTRACT OF THE DISCLOSURE

The invention relates to a mechanical heart for pumping blood in humans that utilizes ultrasonic mechanical vibrations for obtaining the pumping motion and also increasing the flow of fluids in the circulatory and other systems of the body.

BACKGROUND OF THE INVENTION

This invention relates generally to mechanical hearts for use in humans and more particularly to the method and apparatus for pumping of blood through the circulatory system and other fluids through other systems, by the application of ultrasonic vibratory energy.

The outstanding and unexpected results obtained by the practice of the method and apparatus of the present invention, are attained by a series of features, steps and elements, working together in inter-related combination, and may be applied to biological organisms in general and particularly the vascular system of humans, and hence will be so illustrated and described.

Before discussing the details of the present invention it might be best to briefly review the anatomy of and the factors related to the human heart, including associated circulatory system, and the manner in which it performs its function.

The heart's whole purpose is to pump blood through the body at a speed and pressure called for by the varying activities and changing environment of the individual. Every minute it moves a little better than a gallon of blood (the body's whole volume is six quarts) and in a day the heart pushes from five to ten tons of blood through our blood vessels. This blood carries oxygen and food for the cells, deposits waste products in the filtering system of the kidneys and then returns to the heart to be pumped to the lungs, where a new supply of oxygen is exchanged for carbon dioxide, then back to the heart it goes for another trip to the cells.

The heart will vary in weight and size with the weight and size of the individual. In adults it will range from half a pound for a small woman to three quarters of a pound for a large man. It is shaped something like an oversized ripe fig. At the heart's widest point it will vary from a little more than four and one half inches, in a small woman, to six inches, in a large man. It fills a fair proportion of the chest cavity and the rib cage protects part of it, with the back of the heart reaching to less than an inch from the spinal column. In most of us the heart rests upon our diaphragm and is raised and lowered slightly when we breathe. It is composed chiefly of muscle in which are embedded blood vessels and is fed like all other organs by its own network of arteries. Its position in the chest cavity is somewhat more to the left than to the right and about two thirds of it is actually more on our left side.

The heart is composed of four chambers. The two front ones being somewhat larger and containing thicker walls than their neighbor on the right. These are called the right and left ventricles. Behind them are two smaller, more thinly walled chambers, called the right and left auricles. The entire heart is lined with a thin delicate membrane

known as the endocardium. Between the auricles and ventricles this tissue extends inward and thickens to form a wall. In this wall there are two roughly circular openings connecting each auricle with its corresponding ventricular which are completely closed by means of a system of valves during the contractions of the heart.

This valve system is one small part of the truly intricate and amazing parts of our heart. These valves act in such a way as to permit the flow of the blood in only one direction, if they were not present much of the blood in the ventricles would flow back into the auricles at each contraction of the heart instead of into the lungs. These valves are called the auriculo-ventricular or A-V valves. There are also valves in the arteries that close while the ventricles are being filled so that the blood will not run back from the arteries into the ventricles. These are called semilunar valves.

In addition to these valves between the auricles and ventricles, there is a much thicker wall composed of muscle that separates the two ventricles from each other. This wall is known as the interventricular septum and extends from top to bottom and from front to back. The two auricles are separated from each other by a thinner membranous wall, thus the blood can't pass directly from one side of the heart to the other. The outer wall of the chambers is the heart muscle itself (the myocardium) which has as its function contraction and relaxation. This does the pumping of the blood which is commonly known as the heart beat. Around the myocardium is the pericardium a tough fibrous sac, which is tougher than the protective coverings of any other organs.

Springing from the top of the left ventricle and bending into a sharp arc is the biggest of the body's blood vessels known as aorta. Branching down from the aorta are coronary arteries that go back into the heart muscle and feed it. The pulmonary artery emerges almost alongside the aorta from the right ventricle and it passes through the arch formed by the aorta. It is called an artery yet it is the only one that does not carry oxygenated blood. The pulmonary artery's main function is to conduct the used blood from the heart to the lungs to have the oxygen replenished. To balance these two outgoing vessels there are six that lead into the heart, two into the right and four into the left.

During life the heart never rests. Its whole cycle takes less than one second and there are seventy to eighty beats in one minute in the average normal heart. This is speeded up during periods of intense emotion, such as during fear or extreme anxiety as well as during intense physical activity. Thus, if you live seventy years and have an average heart rate of eighty per minute, it will be repeated nearly three billion times; perhaps more, because the heartbeat in childhood is faster than it is in later life. Hearts are individuals just as every one of us is an individual, and the heart acts just like individuals. The beats of the heart change according to how much activity you happen to engage in. The flow of blood from the heart increases in direct proportion to the faster heartbeat.

To understand the workings of the heart perhaps the processes of the circulatory system should be now briefly described. The circulatory system carries out the distribution within the body. The amount of blood contained in this system varies with the size of the individual, in adults eleven pints is the average. It flows rapidly, more rapidly in its way to nourish the cells, slower on its return. The network which carries oxygenated blood is composed of arteries which branch out from a main trunk through large branches to smaller ones called arterioles, and finally to tiny vessels, and capillaries. Veins carry the blood back. There are three vital pieces of machinery which keep the blood coursing through the vessels with a proper supply of

nourishment. One is the heart which is the pump that keeps the circulation going and keeps it changing with the needs of the body. The second part is the kidneys, which provide a filtering mechanism. The third piece of "machinery" is the lungs which operate as a "refueling" station where oxygen is taken on. This system is a unit that functions as a whole but the heart supplies the driving force of this whole system.

Being able to understand our heart has helped us in many ways. First of all we can see how the circulatory system can serve an individual throughout his life and we can see more confidently how it can do so throughout his life without any difficulty. Then secondly we can discover the trouble spots when anything does go wrong. There are of course many areas of this intricate mechanism that may go off course and cause the individual some trouble, varying in the degree of trouble according to the area that does not function properly. Many people are caused needless anxiety when they talk themselves into "palpitations" and "murmurs." These things happen occasionally to even perfectly healthy hearts and often needless fears are built up by the individual who may think he or she may have something drastically wrong with their heart.

Of course there are many dangerous irregularities of the heart that can eventually lead to serious danger in regards to the proper functioning of the heart and in some instances requiring a heart transplanting of either a heart of another human or a mechanical heart. The above background information is intended to indicate the complex functional characteristics of the heart and accordingly of any mechanical ultrasonic heart which is to replace it.

Since this invention also deals with the pumping of fluids through the vascular and other systems let us also review briefly generally known facts of circulatory system and the accumulation cholesterol bearing and other foreign deposits in the vascular system. A human being begins life quite literally with a pure heart, but cholesterol and other substances not yet fully understood can begin to coat the inner layer of blood vessels. Once this coating process begins, the artery's normally smooth inner surface roughens and buckles. Its natural elasticity gradually disappears, and it no longer helps move blood into the body. The pressure needed to force blood through these narrowing corridors slowly rises. Overworked, the heart becomes a candidate for cardiac trouble. Laboring to sustain life under the accumulation of fatty deposits contained in the arteries, the muscles of the heart thicken and lose their precious elasticity.

The cholesterol is usually deposited in the arteries, and this is perhaps because there the blood stream is at its swiftest and cholesterol is most easily torn off its carrier. Once cholesterol begins clogging up the inner surface of an artery, it narrows the bore and thus increases the blood pressure at that point. Furthermore, it reduces the elasticity of the arterial wall so that there is increased danger of a break under the additional stress. Furthermore, the internal surface becomes rough and ragged, offering opportunities for blood clots to form and perhaps block off a particular vessel entirely. This last is called thrombosis. When thrombosis occurs in the coronary arteries that feed the heart, the result is what is commonly known as a "heart attack." The condition of cholesterol settling out on the inner walls of the arteries is known as atherosclerosis. Now that infectious diseases have been brought under such good control by means of vaccination, community hygiene and antibiotics, atherosclerosis has become the number one killer of mankind in the western world.

Although surgeons today can offer certain solutions such as to transplant new sections of human arteries to replace those clogged up, or use artificial tubing made of synthetic materials, I have discovered that in many instances removal of major portions of blood vessels is not required and that the implanting or coupling to the blood vessel of an ultrasonic transducer in accordance with the

present invention provides a sufficient "booster" to overcome the accumulated cholesterol.

Having thus described the heart and the problems associated with the circulatory system it is apparent that there are instances that in order to maintain the life of the human nothing less than a transplant of the entire heart is required, yet in other instances a substitution of two chambers of the left or right side is all that may be required. For those humans in which the heart is not functioning with enough pumping force to assure proper circulation, or the arteries are cholesterol infested, then a "booster" is required somewhere within the system to obtain ample circulation and all of which may be accomplished in accordance with the present invention.

PRIOR ART

In the past mechanical hearts have been developed for use in human beings and animals as either a total replacement, or designed to take part of the work-load off the natural heart. Common to these devices, as discussed below, is the fact that gross moving parts are required to be used that are prone to fatiguing and fracturing after prolonged use. This is in contrast to the present invention in which no gross moving parts are contemplated thereby avoiding one of the basic detriments of the prior art devices.

The flexible membranes of the prior art devices generally relied on to obtain the pumping action are of a rubber or plastic material that can fracture, due to wear or puncture and spring a leak. In addition, the need for a supply of gas to operate the pump, besides a possible leak developing, also accounts for another element of unreliability to be accounted for.

Briefly, one prior art device is a nearly spherical chamber the size of a small apple. Inside is a flexible membrane that moves back and forth from one hemisphere to the other as gas is alternately pumped in and withdrawn from the space on one side of the membrane. As the membrane moves to one side of the chamber, blood from the left atrium (the heart's upper chamber) fills the artificial heart. When gas flows back into the artificial heart, the membrane moves to the opposite hemisphere, forcing the blood out. A valve keeps it from moving back towards the heart, so it flows forward into one of the body's major arteries.

Another device which is used in series with the natural heart, is installed across the arch of the aorta, and all blood that flows through the body must pass through both the natural heart and the booster heart, with each doing some of the pumping. The device includes a rigid outer case and an inner lining. When gas is forced between the inner and outer layers, the flexible inner membrane alternately collapses and expands. In operation, as the natural left ventricle expels blood, the booster heart expands to receive it. Thus, the natural heart pumps blood into an expanding chamber, and is required to do relatively little work. When the heart's stroke is completed, a pulse of gas into the artificial heart presses on its inner lining, forcing blood out. Since the heart's valve has closed, blood can't flow back into the heart and must flow out through the body.

Electrodes sewn into the natural heart sense the heart's rhythm. These electrical signals are used to trigger the pumping of the booster heart and keep it in perfect synchronism with the natural heart.

The balloon pump device has also been used and consists of a rubbery balloon on the end of a long tube, whose other end is attached to the pump. The great artery in the leg is opened and balloon and tube are pushed upward into the aorta, where the balloon is started pulsating. As it collapses, it makes room where there was none before, just as the natural heart is expelling its blood. As with the booster heart, the natural heart is pumping blood into an expanding space. Then, when the heart's valve closes

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to prevent backflow, the balloon expands, forcing blood through the body.

OBJECTS OF THE INVENTION

An object of the present invention is to provide an improved method and apparatus utilizing ultrasonic energy to pump fluids and viscous materials through the various systems of human beings and other animals.

Another object of the present invention is to provide an ultrasonic mechanical heart for use in humans and animals in replacement of or an assist to their regular heart.

Another object of the present invention is to provide an ultrasonic mechanical heart that may be implanted in a human and powered by battery.

Another object of the present invention is to provide an improved method and apparatus for providing a "boost" to the flow of blood within the circulatory system at selected portions thereof.

Another object of the present invention is to provide an improved method and apparatus for affecting the flow of fluids through the circulatory, digestive, excretory, respiratory, reproductive and other systems in humans and other animals.

Other objects and advantages of this invention will become apparent as the disclosure proceeds.

SUMMARY OF THE INVENTION

The present invention provides methods and procedures for enhancing the flow of fluids, which as the term is used herein also includes solid particles contained in a liquid mixture, and which may be of various viscosities and admixtures, by the use of mechanical vibrations which may be externally or internally coupled to any system of a biological organism suitably adapted to enhance the flow of fluid therefrom or therethrough. The ultrasonic transducers used for generating the mechanical vibrations may be battery powered.

The present invention provides methods and procedures for obtaining the circulation of blood in the human body in a manner to either completely or partially discontinue using, and in turn removing, the heart of a human, or utilize it in conjunction with an ultrasonic heart for obtaining the increased circulation. The procedures of the invention can be practiced in almost all instances by resorting to surgical techniques in which access to the portion of the anatomy where the difficulty exists is obtained with complete freedom, thereby permitting the procedure to be practiced throughout the various portions of the cardio-vascular and other systems.

The present invention accomplishes the beneficial results described herein by the application of sonic, transonic or ultrasonic vibrational wave energy directly or indirectly to the fluid, such as blood, at its location in the patient's body. It has been determined that the circulation of the individual may be maintained by coupling to the circulatory system the ultrasonic transducer. In practicing the invention, surgical procedures are involved to expose suitable arteries or veins which are connected to the ultrasonic motor, such that the rate or pressure of blood flowing therethrough is increased. This coupling to the cardio-vascular system is obtainable in almost all critical areas thereof which are subject to poor circulation and can be generally reached. The ultrasonic transducer is also small enough to be implanted in the body and powered by battery. Accordingly, as a consequence of the accessibility of almost all parts of the cardio-vascular system it is possible to propagate wave energy in a manner to increase the circulation by the efficient transfer of energy into the blood in a mechanical manner.

BRIEF DESCRIPTION OF THE DRAWINGS

Although the characteristic features of this invention will be particularly pointed out in the claims, the invention itself, and the manner in which it may be made and used,

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may be better understood by referring to the following description taken in connection with the accompanying drawings forming a part hereof, wherein like reference numerals refer to like parts throughout the several views and in which:

FIG. 1 is a schematic representation of a human heart to help illustrate various aspects of the present invention;

FIG. 2 is a view of a human having an ultrasonic heart implanted therein;

FIG. 3 is a cross-sectional view, in schematic form of an ultrasonic pumping device, that may be used as a mechanical heart, having chambers for containing a supply of fluid therein;

FIG. 4 is a cross sectional view in schematic form, of an ultrasonic pumping device having one transducer associated with each chamber;

FIG. 5 is a cross-sectional view, in schematic form, of an ultrasonic pumping device having two transducers associated with a single chamber;

FIG. 6 is a cross-sectional view, in schematic form, of an ultrasonic pumping device having a transducer and valve coupled to a chamber;

FIG. 7 is an enlarged cross-sectional view of one form of transducer construction that may be used in accordance with the invention;

FIG. 8 is an enlarged cross-sectional view of another form of transducer construction that may be used in accordance with the invention; and

FIG. 9 is an enlarged cross-sectional view of another form of transducer construction implanted within a system of a human being or animal.

PREFERRED EMBODIMENTS

Referring to the drawings and particularly to FIG. 1 thereof, we have a schematic representation of the heart of a human being indicated by the reference numeral 10 and seen to be a hollow organ with certain properties. Its tough, muscular wall (myocardium) is surrounded by a fiberlike bag (pericardium) and is lined by a thin, strong membrane (endocardium). A wall (septum) divides the heart cavity down the middle into a "right heart" and a "left heart." Each side of the heart is divided again into an upper chamber (called an atrium or auricle) and a lower chamber (ventricle). Valves regulate the flow of blood through the heart and to the pulmonary artery and the aorta.

The heart is really a double pump. One pump (the right heart) receives blood which has just come from the body after delivering nutrients and oxygen to the body tissues. It pumps this dark, bluish red blood to the lungs where the blood gets rid of a waste gas (carbon dioxide) and picks up a fresh supply of oxygen which turns it a bright red again. The second pump (the left heart) receives this "reconditioned" blood from the lungs and pumps it out through the great trunk-artery (aorta) to be distributed by smaller arteries to all parts of the body.

FIG. 2 illustrates schematically the ultrasonic heart or device 11 in accordance with the present invention for use with a human being 12 for effecting fluid flow, although it may be used with an animal or biological organism, and includes ultrasonic generating means 14 for producing ultrasonic mechanical vibrations or mechanical elastic energy waves, and may include transducer means 15 communicating with chamber means 24, that may be implanted in the human being 12 by coupling means 27 and coupled to power supply means 18 that may be positioned externally of the body 12, or internally by power cable 20. The power supply means 18 may be battery powered and include the necessary ultrasonic generator well known in the art. It may be supported by a strap (not shown) exteriorly of the human 12. The ultrasonic device 11 is illustrated in FIG. 2, is connected to the cardio-vascular system, but it is appreciated that any system of a human being or animal having fluid flow therethrough may have the device of the present invention

associated therewith. By way of example, and not limitation, we have the group of circulatory, digestive, excretory, respiratory and reproductive systems that may be coupled to the device of the present invention.

Referring to FIG. 3, we have illustrated, in somewhat schematic form, an ultrasonic mechanical heart 11, in which related equivalent mechanical portions are viewed such that the total function of the mechanical heart 11 is essentially equivalent to what has been illustrated in FIG. 1. The mechanical heart 11 includes chamber means 24, which may be made of plastic such as nylon, for retaining a supply of blood. To duplicate the heart, the chamber means 24 includes right chamber means 25 and left chamber means 26. The chamber means 24 includes coupling means 27 which may be integrally formed therewith to connect the chamber means 24 to the cardio-vascular system such that it is in communicating relationship therewith and adapted to receive the fluid 28 in the form of blood therein. Blood 28 flowing into the heart 11 flows in the direction of arrow 21 and exits into the cardio-vascular system in the direction of arrow 23. The chamber means 25 may include a first chamber 30 having an inlet opening 32 at one end thereof extending through inlet T-shaped conduit 34 forming part of the coupling means 27 and provided in the wall of the first chamber 30 which is in turn connected to the inferior vena cava 36 and superior vena cava 38 such that a continuous flow of fluid 28 may enter through the inlet opening 32 and accumulate in the first chamber 30 which is the equivalent of the right atrium. The first chamber 30 is in communicating relationship with a second chamber 40 which is the equivalent of the right ventricle, and has an outlet opening 42 extending through outlet conduit 44, forming part of the coupling means 27, which is connected to the pulmonary artery 45 in any conventional manner as by suturing or bonding. Between the respective first chamber 30 and second chamber 40 we have a wall 46 and mounted with respect to the wall 46 and in communicating relationship thereto is transducer means 15 so that blood entering the first chamber 30 may be stored therein to provide a continuous supply thereof to the transducer means 15 which pumps the blood into the second chamber 40 and out through the outlet opening 42. The ultrasonic transducer 15 has power cable 20 connecting same to the power supply means 18 which as illustrated in FIG. 2, may be contained exteriorly of the body.

In a similar manner the left side of the heart may be duplicated and includes chamber means 26 containing a left first chamber 31 equivalent to the left atrium, and a left second chamber 41 equivalent to the left ventricle with a wall 47 therebetween having the ultrasonic transducer 15 mounted with respect thereto. An inlet opening 33 extending through inlet conduit 35 which extends through the upper wall for coupling to the pulmonary vein 49. At the opposite wall of the left ventricle which is the second chamber 41 we have an externally extending outlet conduit 50 having an outlet opening 52 there-through, which is secured to the aorta 54.

The inlet and/or the outlet openings of the chamber means 24 may have transducer means 15 or conventional mechanical valves in communicating relationship therewith, as illustrated with respect to the outlet opening 52 of the second chamber means 41. Transducer 15 is positioned so that the blood 28 must pass therethrough before exiting into the aorta 54, and is connected by cable 20 to the power supply means 18. The respective transducers 15 associated with the lower chamber may be synchronized to control the rate of fluid flowing into and out of the left chamber means 26. This synchronization may be established, by procedures known in the art, to obtain a selected phase relationship between oscillations of the respective transducers 15. If a phase relationship of 0° is established between the oscillations of the respective transducer means 15 then they vibrate in phase with each other and continuously pump blood to the car-

dio-vascular system. On the other hand they may operate as an electrical valve in that the transducer 15 in wall 47 is first open and pumps blood into the left second chamber 41 for storage therein, during which time the transducer 15 at the outlet opening 52 is closed or non-energized. When the left second chamber 41 is filled up then the transducer 15 at the outlet opening 52 is energized and the transducer 15 in wall 47 is closed. As hereafter described, although the transducer 15 has passage means therethrough, generally always open, the flow through it when it is not energized is so minimal as to be considered "closed," as compared to the flow through when it is vibrated.

As seen above the right chamber means 25 is the equivalent of the right side of the heart and the left chamber means 26 is equivalent of the left side. Although in certain instances the entire right chamber means 25 and left chamber means 26 will be coupled together and utilized it is possible to use either the right section or the left section independently of the other and in a sense to assist a faltering heart that we do not wish to remove entirely but as an "assist" or a "booster" for the damaged section. The chamber means 24 can be interconnected with a damaged heart, in series or parallel, which may be preferable to replacing it. Accordingly, the chamber means 24 may be used in conjunction with either half of or the entire human heart and may be either implanted or supported exteriorly of the human.

The embodiment of the ultrasonic device 11a illustrated in FIG. 4, is such that the chamber means 24a includes a right chamber means 25a and left chamber means 26a, and the blood 28a may be properly maintained in the right chamber means 25a so that there will continuously be a supply on hand. In view of the fact that the pumping action is in a sense continuous, since as the term "ultrasonic" is herein defined it is intended to include energy from the frequency range of generally 500 cycles per second to 1,000,000 cycles per second, so that a separate chamber for storage might not always be required. However, for continuous application the upper limit should not exceed 600,000 cycles per second, and the preferred frequency range for continuous pumping is approximately 10,000 cycles per second to 600,000 cycles per second.

Accordingly, as seen in FIG. 4, the ultrasonic heart 11a is seen consisting of chamber means 24a including a right chamber means 25a and left chamber means 26a joined together by connecting means 55a which may be in the form of a plate 56a welded to the respective walls thereof to maintain them in fixed relation to each other, with coupling means 27a to retain the chambers in position with respect to the cardio-vascular or other system it is used in conjunction with. The right chamber means 25a is equivalent essentially to the right ventricle and has at its inlet opening 32a formed by conduit 34a the ultrasonic transducer 15a mounted therein in energy transferring relationship to the blood 28a as it passes therethrough, to subject it to vibrating energy. The inlet conduit 34a forms part of the coupling means 27a and may be connected to the superior vena cava and inferior vena cava. At the opposite end of the right chamber means 25a through the wall thereof we have an outlet opening 42a formed by conduit 44a which in turn is connected to the pulmonary artery such that the fluid 28a entering through the inlet opening 32a in the direction of arrow 21a is continuously pumped therethrough until same exits via the outlet opening 42a as indicated by arrow 23a.

In this manner the ultrasonic transducer 15a coupled to the power supply means 18a by cable 20a functions in such a way that the energy is continuously forcing the fluid material 28a out from within the right chamber means 25a into the pulmonary artery. In a similar manner the left chamber means 26a which is the equivalent of the left ventricle and functions in the same manner as

the right chamber means 25a in that fluid 28a flowing in the direction of arrow 21a enters via entrance opening 33a through the conduit 35a into the ultrasonic transducer 15a mounted to extend from a wall of the left chamber means 26a and which fluid 28a exists through an outlet opening 52a formed by outlet conduit 50a in the direction of arrow 23a. The device 11a as seen in FIG. 4, may be similarly implanted in vivo or mounted exteriorally of the person using it as a replacement of the human heart or as an assist thereof with the human heart not being removed.

FIG. 5 illustrates another embodiment of the ultrasonic device 11b of the invention in which a pair of ultrasonic transducers 15b are used with respect to the chamber means 24b. One transducer unit 15b is provided at the entrance opening 32b such that it accepts the flow of fluid 28b in the direction of arrow 21b entering conduit 34b from the cardio-vascular system. This fluid 28b is accumulated in the chambers means 24b which is equivalent of essentially the right ventricle. Mounted at the exit or outlet opening 42b is another ultrasonic transducer 15b which extends through the wall of the chamber means 24b and is coupled to the conduit 44b which is connected to the pulmonary artery. Both of the respective ultrasonic transducers may be connected to a single power source 18b by cables 20b. By utilizing two ultrasonic motors, the first one in a sense acts as an ultrasonic valve in that it has the ability due to its frictionless surfaces when powered to provide a minimum of friction and therefore permit a greater degree of fluid to continuously enter into the chamber means 24b and at the same time the second transducer 15b can pump the fluid out from within. When the ultrasonic transducer is not energized the orifice opening therein is such that none or a minimum of fluid passes therethrough. This can be accomplished by using a plurality of small apertures through which the blood will not flow unless the transducer is energized. By proper synchronization of the respective cycles of the transducers as described above, it is possible to control the rate of inflow in the direction of arrow 21b and the rate of outflow from the chamber means in the direction of arrow 23b. Two or more chambers means 24b illustrated in FIG. 5, may be coupled together in series or parallel for use with humans or animals.

FIG. 6 illustrates an embodiment of the ultrasonic device 11c, similar to FIG. 5, except that the chamber means 24c at its inlet opening 32c contains a conventional mechanical valve 58c which functions to permit the flow of fluid 28c in the direction of arrow 21c entering through the inlet conduit 34c into the chamber means 24c. At the outlet end we have an outlet opening 42c and an ultrasonic transducer 15c mounted in communication to the chamber 24c and coupled to the outlet conduit 44c so that the fluid material 28c flowing in the direction of arrow 23c exits therefrom at controlled flow rates.

Obviously, the schematic representations illustrated in FIGS. 3-6 are such that the shape, configuration, size and even the materials of the respective chambers will vary due to the size, age, etc., of the individual involved and it should be appreciated that the respective position of the inlet and outlet openings are such that will be determined with the particular use involved. Accordingly, it might even be desired in certain instances to place both on the same wall of the respective chamber means. Their position as shown is merely illustrative to indicate that one or more inlet, and outlet openings may be utilized in conjunction to obtain the proper functioning of a particular total ultrasonic heart or other pumping device. The various sizes of the ultrasonic transducer or motor will also be determined by the age and condition of the individual receiving same and if it is to act as a partial replacement or supplement, or completely replace the entire human heart.

In order to obtain the desired transmission and resultant flow of fluid in the human body through various systems it is possible to use a variety of electromechanical devices

that will effectively function under the particular environmental conditions required. The ultrasonic motor may be one of a variety of electromechanical types, such as electrodynamic, piezoelectric or magnetostrictive well known in the art.

The transducers utilized in accordance with the invention should be of the design to have a geometric bias to produce an asymmetry of the mechanical vibrations to obtain rectification of same to produce a flow in a single direction of the fluid. By producing a non-linearity of mechanical vibratory motion we do not obtain a cancellation of the vibrations. The asymmetry of vibrations may be produced in various ways to produce the pumping action of the fluid. For example, elliptical vibratory motion, which produces a whipping type of action for the pumping, may be used. Accordingly the vibration pattern may be elliptical, longitudinal, flexural, radial or torsional.

The magnitude or volume V, of pumping by the transducer means is directly related to the frequency of vibration F, area of pumping surface Y, and amplitude of vibration A. The volume V is expressed by the formula:

$$(1) \quad V = A \text{ in.} \times F \text{ cyc./sec.} \times Y \text{ in.}^2$$

for certain nominal values where

$$A = .001 \text{ in.}$$

$$F = 10,000 \text{ cycles per second.}$$

$$Y = 1 \text{ in.}^2$$

$$(2) \quad V = .001 \text{ in.} \times 10,000 \text{ cyc./sec.} \times 1 \text{ in.}^2$$

$$(3) \quad V = 10 \text{ in.}^3/\text{sec.}$$

Converting this to gallons per minute we have

$$(4) \quad V = \text{in.}^3/\text{sec.} \times 60 \text{ sec./min.} = 600 \text{ in.}^3/\text{min.}$$

$$(5) \quad V = \frac{600 \text{ in.}^3/\text{min.}}{231 \text{ in.}^3/\text{gal.}} = 2.6 \text{ gal./min.}$$

The above merely illustrates the magnitude of pumping action available with a relatively small transducer having a one inch square pumping surface. Since every minute the average heart moves a little better than a gallon of blood per minute it is seen that the required flow can be obtained with a transducer having a .5 in.² pumping surface at the above frequency and amplitude of vibration.

Another generic quality of ultrasonics is its known ability to decrease friction with respect to a fluid flowing across its boundary. This factor which helps minimize friction at the interface of the vibratory surface and fluid friction between the blood and mechanical device is important since friction has been considered a cause for forming blood clots with respect to the prior art devices.

FIGS. 7 and 8, illustrate two forms of ultrasonic transducers for use in accordance with the present invention. For example, the ultrasonic transducers or motors for pumping may be of the type disclosed in U.S. Pats. Nos. 3,211,931, 3,361,067 and 3,378,814. As illustrated in FIG. 7 we have an ultrasonic motor 15d that may be in the form substantially as disclosed in U.S. Pat. No. 3,378,814, and mounted to extend within the chamber means 24d by extending inwardly therein and having the ultrasonic motor 15d supported at one end in connection with the wall 59d. Mounting means 60d, which may also act as sealing means, supports the transducer 15d such that vibratory elastic energy waves are not transmitted to the wall 59d of the chamber means 24d and the rest of the body. The outlet conduit 44d is conventionally secured to the wall 59d on the exterior surface thereof such that the energy is not transmitted to it as well, and the fluid exits through outlet opening 42d in the direction of arrow 23d.

The transducer 15d is designed to include transmitting means 61d, to be set into vibration in a given direction with passage means forming passageway 62d extending therethrough and through which the fluid flows as it is pumped. The passageway 62d forms a flow path communicating at one end with the chamber means 24d by openings 64d extending transversely to the axis of the

transducer 15d so that blood may enter in the direction of arrow 31d and flow therethrough and be subjected to vibratory energy to obtain the pumping action with the blood exiting in the direction of arrow 23d through the outlet opening 42d. The transmitting means 61d includes a body portion generally designated as 66d having ends generally designated 68d and 70d. It is desired that the effective vibrations be produced at the end 70d thereof, which may be obtained in accordance with U.S. Patent No. 3,378,814. The body portion 66d comprises a tubular portion generally designated 72d and a head 74d at one end thereof. The tubular portion 72d comprises a solid body with the passage 62d therethrough, the passage extending from the end 70d to the rear face 76d of the head 74d, the head 74d in effect closing the inner end of the passage 62d and having a front face 78d at the unit end 68d designated to produce the effective vibrations as indicated by the arrow 80d. The tubular portion 72d in the embodiment of FIG. 7, is defined by end portions 82d and 84d which may be formed of any suitable structural material such as plastic, aluminum, or steel between which a ring 85d of electrostrictive material is sandwiched.

The ring 85d having electrodes 86d and 88d on opposite faces thereof, to which leads 90d and 92d are electrically connected from the power source 18d. When an alternating electric voltage is applied to the leads 90d and 92d the electrostrictive material of which the ring 85d is formed will cause the ring to vibrate in a longitudinal mode, from left to right as viewed in FIG. 7. These vibrations will be transmitted by the tubular portions 82d and 84d, and the head 74d respectively, which portions form the transmitting means 61d. By providing one or more apertures 64d it is possible to obtain a constant flow of the fluid within the passageway 62d, which also forms part of the chamber means such that the fluid as it continues to flow therein is continually pumped out by the rapid vibratory forces applied by the end section 74d.

Inherent in certain frequencies of vibration is cavitation action and to maintain same at a minimum it has been found desirable in certain instances to apply vibration damping means 95d in the form of a liner or coating 96d from a plastic such as nylon, such that a minimum of cavitation energy is transmitted to the fluid. The liner 96d may be secured by a bonding agent to the transmitting means 61d.

FIG. 8 illustrates another form of ultrasonic device 11e which includes transducer means 15e contained within chamber means 24e by mounting means 60e to the wall 59e of the chamber means 24e. The outlet conduit 44e is secured at the outer side of the wall 59e such that the outlet opening 42e is in coaxial alignment with the passageway 62e which extends through the transducer 15e to permit a flow of blood to enter in the direction of arrow 21e and exit in the direction of arrow 23e. The mounting means 60e encloses the transducer means 15e which is secured thereto and includes a tubular sleeve 98e secured to the wall 59e at one end and a flange 99e at its opposite end secured to the front face 78e of the transducer means 15e. The construction of the transducer in FIG. 8, might be similar to the device illustrated in FIG. 7, except that the inner wall surface of the passageway 62e of the tubular end portions 82e and 84e have pumping magnification or enhancing means 100e to increase the area of pumping and to obtain vibratory surfaces normal to the flow of fluid through the transmitting means 61e in energy transferring relation thereto. One form of pumping magnification means 100e may include a plurality of axially spaced apart recesses in the form of annular grooves 101e having a substantially vertical wall surface 102e and an inclined surface 103e extending from the bottom of the recess in the direction of the flow of fluid as indicated by arrow 23e. This effectively produces an increased surface area in a plane substantially normal to the direction of movement of the fluid such that the pumping action is further enhanced and continued throughout the entire

axial length of the transducer means 15e. In a similar manner the leads 90e and 92e from the ring 85e are connected to the power supply means 18e.

In the above embodiments the inventor has generally illustrated the application of the invention as it relates to replacing all or part of the heart in a biological organism, such as a human. In a similar manner it is appreciated by the inventor that there are certain areas in which certain veins, arteries or other ducts of the human are not receiving proper amounts of fluid. In the vascular system this is either due to the malfunction of the heart or due to perhaps cholesterol buildup or hardening of the arteries as is common in many individuals. Accordingly, the inventor has discovered that it is possible to essentially provide a booster to the supply in the circulatory system which may be implanted at various locations, for example, one in each leg such as to assure the proper continued flow of the blood throughout that particular body portion. In this manner it is possible to permit the heart to remain untouched, even though it might be somewhat damaged and not functioning properly, and provide the ultrasonic transducer in selected portions of the body and have some powered by the supply means as discussed above.

Accordingly, as illustrated in FIG. 9, an ultrasonic device 11f including a transducer 15f is shown implanted in a vessel of a human or animal such as a vein or artery 105f which forms the conduit and has been severed to provide respective end portions 106f and 107f in spaced apart relationship with each other. Positioned between the adjacent end portions 106f and 107f is the ultrasonic device 11f which joins the respective ends of the artery 105f and permits the flow of fluid therethrough but accelerates it to the extent that it assures the portion of the body that it is supplying a proper continued supply of fluid. The device may be of similar construction as illustrated with respect to FIGS. 7 and 8, and include transducer means 15f having transmitting means 61f with a passageway 62f extending therethrough and in which end sections 82f and 84f are sandwiched between an electrostrictive material in the form of a ring 85f having electrodes 86f and 88f on opposite axial faces thereof, to which leads 90f and 92f are electrically connected and in turn to the power supply source.

To prevent the vibratory energy from being transmitted to the remaining portion of the system the entire device, may be embedded in a poxy or other suitable enclosure to avoid the energy transmission. But as seen in FIG. 9, we have radical mounting flanges 108f associated with their respective end portions 82f and 84f which rings are located substantially at a longitudinal node of vibration such that a minimum of vibratory energy is transmitted to the mounting means 60f which is seen to include an adaptor including an annular sleeve section 98f, vertical side section 99f, and mounting annular section 110f which is secured to the artery end sections 105f and 106f using conventional techniques. The respective mounting means is duplicated at each end and accordingly is used as such.

Pumping magnification means 100f is provided within the passageway 62f and includes the annular grooves 101f. The grooves 101f may terminate in fingers 112f designed to vibrate with a flexural or elliptical pattern to obtain a geometric bias to produce an asymmetry of the mechanical vibrations to obtain rectification of same to produce the flow in a single direction with the inflow as indicated by arrow 21f and outflow by arrow 23f.

It is obvious that the embodiment illustrated in FIG. 9 can be placed in the desired position and utilized as a booster if and when required for any and all systems within a human through which fluid or other viscous materials must be moved. Accordingly, it may be implanted in the digestive system as part of the intestinal tract or to

pump glandular secretions such as bile, or mix fluids together, or change their viscosity or effect other characteristics by treatment with ultrasonic energy. Another example is to break up blood clots by subjecting same to ultrasonic energy when a blood clot has been detected or determined.

The materials of which the respective chambers may be constructed will definitely vary and can be made of materials that will withstand the environmental conditions associated therewith, such as from plastic or metal. Although the electrostrictive types of units have been illustrated it is appreciated that the apparatus may be of various types and design either magnetostrictive, piezoelectric or others which are well known in the art and need not be further discussed herein.

While only a few procedures for practicing the invention have been described herein, it will be apparent that needs for increasing the circulation of flow in any location are susceptible to the procedures of the invention, if they can be exposed to ultrasonic vibrations. As used herein, ultrasonic includes the range of frequencies, including high sonic, transonic and low ultrasonic and high ultrasonic ranges and the use of any of these terms should be considered to be generic to all such frequencies.

Although illustrative embodiments of the invention have been described in detail herein with reference to the accompanying drawing, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein without departing from the scope or spirit of the invention.

What is claimed is:

1. A method of effecting the flow of fluid in a body of a human being or an animal, comprising the steps of:

- (A) producing ultrasonic mechanical vibrations with transducer means, in the range of approximately 10,000 cycles per second to 600,000 cycles per second,
- (B) coupling said transducer means to a system of the body,
- (C) implanting said transducer means within the body,
- (D) mounting said transducer means to said system such that the ultrasonic vibrational energy generated therein is substantially contained within said transducer means and not transmitted to the surrounding portion of the body,
- (E) transmitting said ultrasonic mechanical vibrations to the fluid passing through said system of the body, whereby the flow of the fluid therethrough is enhanced, said mechanical vibrations are characterized by having a geometric bias so as to obtain the flow of the fluid in a single direction, and
- (F) selecting the intensity of said vibrational energy to produce a minimum of cavitation in the fluid.

2. A method as defined in claim 1, wherein said system is selected from the group consisting of circulatory, digestive, excretory, respiratory and reproductive.

3. A method as defined in claim 1, and further including the step of storing a supply of the fluid in chamber means prior to subjecting it to the mechanical vibrations.

4. A method of effecting the flow of blood in the circulatory system of a human being or an animal in vivo, comprising the steps of:

- (A) opening said circulatory system to gain access thereto,
- (B) coupling to said circulatory system transducer means adapted to be vibrated at a high frequency, in the range of approximately 10,000 cycles per second to 600,000 cycles per second, to generate mechanical elastic energy waves, said transducer means having passage means communicating with a blood vessel of said circulatory system for the blood to flow therethrough,
- (C) energizing said transducer means whereby the blood in said passage means is subjected to said elastic

energy waves and the flow of the blood in said circulatory system is enhanced,

(D) providing chamber means in communicating relationship with said passage means, whereby a quantity of blood may be retained for selected intervals of time, said chamber means having an inlet opening and an outlet opening and said transducer means is in communicating relationship with said outlet opening, and

(E) implanting said transducer means within the human being or animal.

5. A method as defined in claim 4, and further including transducer means in communicating relationship with said inlet opening.

6. A method as defined in claim 4, wherein said chamber means includes:

- (a) a right chamber means including a right first chamber having an inlet opening and a right second chamber having an outlet opening, said respective inlet and outlet openings coupled to said circulatory system,
- (b) a left chamber means including a left first chamber having an inlet opening and a left second chamber having an outlet opening, said respective inlet and outlet openings coupled to said circulatory system, and
- (c) said transducer means mounted in communicating relationship with said respective first and second chambers so that blood entering said first chambers may be retained therein to provide a continuous supply thereof, and said transducer means associated with each of said right and left chamber means pumping the blood into said second chambers for flow out through said outlet openings.

7. A method of effecting the flow of blood in the circulatory system of a human being or an animal in vivo, comprising the steps of:

- (A) opening said circulatory system to gain access thereto,
- (B) coupling to said circulatory system transducer means adapted to be vibrated at a high frequency to generate mechanical vibrations of elastic energy waves, said transducer means having passage means communicating with a blood vessel of said circulatory system for the blood to flow therethrough,
- (C) energizing said transducer means, whereby the blood in said passage means is subjected to said energy waves and the flow of the blood in said circulatory system is enhanced,
- (D) providing chamber means in communicating relationship with said passage means, whereby a quantity of blood may be retained for selected intervals of time, said chamber means having an inlet opening and an outlet opening and said transducer means is in communicating relationship with each of said openings, and
- (E) said respective transducer means are connected to operate in phase relationship to each other to control the rate of flow respectively through said inlet and outlet openings.

8. A method as defined in claim 7, and including the step of selecting the frequency of said vibrational energy to produce a minimum of cavitation in the fluid.

9. A method as defined in claim 7, wherein said mechanical vibrations is selected from the group consisting of longitudinal, elliptical, flexural, torsional and radial vibrations.

10. A method as defined in claim 7, wherein said mechanical vibrations is characterized by having a geometric bias so as to obtain the flow of the fluid in a single direction.

11. A method as defined in claim 7, and further including the step of mounting said transducer means to said circulatory system such that the ultrasonic vibrational

energy generated is substantially not transmitted to the surrounding portion of the body.

12. Apparatus for effecting fluid flow in a body of a human being or an animal, comprising:

- (A) generating means for producing ultrasonic mechanical vibration, said generating means includes transducer means for producing said ultrasonic mechanical vibration, said transducer means including transmitting means to be set into vibration thereby in a given direction, said transmitting means including passage means forming a passageway through which the fluid is adapted to be pumped,
 - (B) means adapted for connecting said generating means in energy transferring relation to a system of the body, whereby the fluid in the system is subjected to vibratory energy and an increased flow of the fluid through the system is produced,
 - (C) magnification means contained within said passageway for increasing the pumping area of said transmitting means, said magnification means includes a plurality of annular axially spaced apart recesses in the wall of said passageway including a substantially vertical wall and an inclined wall tapered from the bottom of said recess in the direction of flow of the fluid through said passageway.
13. Apparatus as defined in claim 12, and further including vibration damping means connected to said transmitting means for reducing the cavitation energy transmitted to the fluid.
14. Apparatus for effecting fluid flow in a body of a human being or an animal, comprising:
- (A) generating means for producing ultrasonic mechanical vibration, said generating means includes transducer means for producing said ultrasonic mechanical vibration, said transducer means including transmitting means to be set into vibration thereby in a given direction,
 - (B) means adapted for connecting said generating means in energy transferring relation to a system of the body, whereby the fluid in the system is subjected to vibratory energy and an increased flow of the fluid through the system is produced, and
 - (C) chamber means adapted for communicating relationship with the body system and connected to said transducer means, and adapted to receive the fluid of the system therein, said chamber means includes an inlet opening and an outlet opening, and said ultrasonic transducer means is respective ultrasonic transducers mounted in communicating relationship with each of said openings, and means synchronizing said transducers to control the rate of fluid into and out of said chamber means.
15. Apparatus as defined in claim 14, wherein said synchronization is established by selected phase relationship between oscillations of said respective transducer means.
16. Apparatus as defined in claim 15, wherein a phase relationship of 0° is established between the oscillations of said respective transducer means so that said transducers vibrate in phase with each other.
17. Apparatus as defined in claim 14, wherein said generating means further includes power supply means connected to said transducer means.
18. Apparatus as defined in claim 14, wherein said ultrasonic transducers have means to transmit ultrasonic mechanical vibration which is characterized in having a geometric bias to produce asymmetry thereof so as to produce the fluid flow in a single given direction.
19. Apparatus as defined in claim 14, and further including magnification means contained within said generating means and forming a passageway for increasing the pumping area of said generating means.
20. A mechanical heart for effecting blood circulation on a body of a human being or an animal, comprising:
- (A) chamber means including an inlet opening and an

outlet opening for receiving a supply of blood therein,

- (B) transducer and generating means for generating ultrasonic mechanical vibration in the range of approximately 10,000 cycles per second to 600,000 cycles per second, and mounted in communicating relationship with said outlet opening and in energy transferring relation to said chamber means, said transducer means having a passage therethrough adapted to receive said blood and having means to transmit said ultrasonic mechanical vibration which is characterized in having a geometric bias to produce asymmetry thereof so as to produce a fluid flow in a single given direction, and
 - (C) coupling means adapted for connecting said chamber means to the cardio-vascular system so as to permit the flow of blood respectively through said inlet opening and outlet opening, whereby the blood is subjected to vibratory energy and a flow of the blood through the cardio-vascular system is produced.
21. A mechanical heart as defined in claim 20, wherein said opening has a mechanical valve mounted in communicating relationship thereto to control the rate of flow of blood into said chamber means.
22. A mechanical heart as defined in claim 20, wherein said chamber means includes:
- (a) a first chamber including said inlet opening,
 - (b) a second chamber including said outlet opening, and
 - (c) said transducer means mounted in communicating relationship with each of said chambers so that blood entering said first chamber may be retained therein to provide a continuous supply thereof and said transducer means pumps the blood into said second chamber for flow out through said outlet opening.
23. A mechanical heart as defined in claim 20, wherein said chamber means includes:
- (a) a right chamber means including a right first chamber having an inlet opening and a right second chamber having an outlet opening,
 - (b) a left chamber means including a left first chamber having an inlet opening and a left second chamber having an outlet opening,
 - (c) said coupling means adapted to connect each of said respective inlet and outlet openings to the cardio-vascular system, and
 - (d) said transducer means mounted in communicating relationship with said respective first and second chambers so that blood entering said first chambers may be retained therein to provide a continuous supply thereof, and said transducer means associated with each of said right and left chamber means pumping the blood into said second chambers for flow out through said outlet openings.
24. A mechanical heart for effecting blood circulation on a body of a human being or an animal, comprising:
- (A) chamber means including an inlet opening and an outlet opening for receiving a supply of blood therein,
 - (B) ultrasonic transducer means mounted in communicating relationship with said openings and in energy transferring relation to said chamber means, and
 - (C) coupling means adapted for connecting said chamber means to the cardio-vascular system so as to permit the flow of blood respectively through said inlet opening and outlet opening, whereby the blood is subjected to vibratory energy and a flow of the blood through the cardio-vascular system is produced,
 - (D) said ultrasonic transducer means comprising respective ultrasonic transducers mounted in communicating relationship with each of said openings, and means synchronizing said transducers to control the rate of blood flowing into and out of said chamber means.

25. A mechanical heart as defined in claim 24, wherein said synchronization is established by selected phase relationship between oscillations of said respective transducer means.

26. A pumping device for effecting the fluid flow in a body of a human being or an animal, comprising:

(A) transmitting means adapted to be set into vibration in a given direction of ultrasonic frequencies for generating mechanical vibration, means for generating ultrasonic mechanical vibrations in the range of approximately 10,000 cycles per second to 600,000 cycles per second,

(B) passage means extending through said transmitting means to form a flow path, means for causing said ultrasonic mechanical vibration to be characterized as having a geometric bias to produce asymmetry thereof so as to produce the fluid flow in a single given direction through said passage means,

(C) input means adapted for coupling said passage means to a system of the body at one end of said flow path, and

(D) output means adapted for coupling the system to the other end of said passage means, whereby the fluid in the system is subjected to vibratory energy and an increased flow of the fluid through the system is produced.

27. A pumping device as defined in claim 26, and further including magnification means contained within said passage means for increasing the pumping area of said transmitting means.

28. A pumping device as defined in claim 26, and further including means for mounting said transmitting means relative to the system to permit a minimum of transmission of vibratory energy thereto.

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