EXTERNAL CARDIAC ASSISTANCE

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Filed: Sept. 28, 1973

Appl. No.: 401,676

U.S. Cl. ............................................................................. 128/64
Int. Cl. ............................................................................. A61H 7/00
Field of Search ..................................................................... 128/24 R, 64, 89 R, 297, 128/299, DIG. 20

References Cited

UNITED STATES PATENTS
2,781,041 2/1957 Weinberg .............................................. 128/24 R
3,654,919 4/1972 Birckwell .............................................. 128/64
3,659,593 5/1972 Vail ...................................................... 128/64
3,745,998 7/1973 Rose ...................................................... 128/89 R

Primary Examiner—Lawrence W. Trapp
Attorney, Agent, or Firm—Charles M. Hogan, Esq.; Melvin E. Frederick, Esq.

ABSTRACT

The flow of blood through the circulatory system of animals is augmented by sequential application of peristaltic pumping pressure along either or both of the legs and/or arms to develop a counterpulse in the aorta. The counterpulse is generated by equipment interconnected with electrocardiographic equipment and synchronized therewith to begin the same time as the beginning of diastole in the patient. A series of bladders arrayed lengthwise along the limb are pressurized simultaneously or in rapid sequence for peristaltic pumping and simultaneously deflated at the end of diastole. Each of the bladders is surrounded by casing means which are rendered rigid during pumping operations to provide a reaction wall and non-rigid between operations for ease of handling and wrapping and unwrapping the limb. The apparatus as a whole provides low real and apparent weight for the patient to carry, high speed of inflation and deflation, low bulk and cost of related pumping equipment, accommodation of a variety of sizes of patients and protection against ejection from the equipment by the pressures generated therein and fail safe mode in case of power failure. The apparatus may be adjusted to suit the pumping needs of different patients with simple checkout and adjustment by the clinical or hospital technician.

12 Claims, 13 Drawing Figures
FIG. 6

FIG. 5

FIG. 4

PATENTED FEB 18, 1975

SHEET 2 OF 4

3,866,604
FIG. 9

FIG. 8

FIG. 7
**Fig. 10**

**Fig. 11**

**Fig. 12**
EXTERNAL CARDIAC ASSISTANCE

BACKGROUND OF THE INVENTION

The present invention relates to external cardiac assistance by developing a diastole synchronized counterpul- 
sel in the aorta. In accordance with the present in-
vention, such counterpulsing is administrable in the field, 
hospitals, clinics and physicians' offices with flex
ible, easily and used, compact equipment.

Externally assisting blood circulation has been de-
scribed in U.S. Pat. No. 3,303,841 to Dennis, U.S. Pat.
No. 3,403,673 to MacLeod, and U.S. Pat. No.
3,654,919 to Birtwell wherein the patient's legs are en-
cased in an hydraulic environment and the pressure on 
the patient's legs is increased through the addition of 
hydraulic fluid to a nondistensible volume to generate 
a counterpulse in the aorta. The hydraulic environment 
transmits applied pressure evenly over all surfaces. 
Uniform pressure over the entire leg surface prohibits 
peristaltic pumping and may also cause "bubble blow-
ing" in the femoral artery, thereby reducing counter-
pulse efficiency. "Bubble blowing" or the bubble blow-
ing effect occurs when a section of the femoral artery 
is prematurely occluded by the application of external 
pressure. As a result of this premature occlusion, blood 
is trapped in the femoral artery and cannot contribute 
to the required counterpulse. In addition, the apparatus 
as described are cumbersome to use and exert addi-
tional external pressure on the leg surface due to the 
weight of the hydraulic fluid.

Pneumatic pumping suits, resembling divers' or a-
nonauts' suits, have also been proposed for diastolic 
augmentation in Cohen et al., "Sequenced External 
Pulsation in the Therapy of Cardiogenic Shock," paper 
published by the Superintendent of Documents in Arti-
ficial Heart Program Conference Proceedings, have 
1,608,293; 2,361,424; 2,528,843; 2,553,504; 
2,781,041; 3,094,116; 3,411,496; 3,548,809; and 
3,659,593. In the apparatus described in the patents, a 
series of non-distensible bladders arrayed along the 
lengths of arms and/or legs are sequentially filled and 
pressurized with air to high pressures (10 psi or more 
in said U.S. Pat. No. 3,659,593), the sequence of pres-
surization of bladders being controlled by a reciprocating 
or rotary valve distributor. An alternate possibility 
for valve sequence is shown in the massage apparatus 
described in French Pat. No. 1,562,252 where a series of 
solenoid valves are time sequence operated to se-
quentially pressurize a series of bladders arrayed along 
the length of a limb.

It is an important object of the invention to provide 
external cardiac assistance with low real and apparent 
weight for the patient to carry.

It is a further object of the invention to provide high 
speed of inflation and deflation consistent with the pre-
ceding object.

It is a further object of the invention to provide low 
weight consistent with one or both of the preceding ob-
jects.

It is a further object of the invention to provide peri-
staltic pumping consistent with one or more of the pre-
ceding objects.

It is a further object of the invention to provide low 
bulk and cost of related pumping equipment con-
sistent with one or more of the preceding objects.

It is a further object of the invention to accommodate 
a variety of sizes of patients and protect against ejec-
tion from the equipment by the pressures generated 
therein, consistent with one or more of the preceding 
objects.

It is a further object of the invention to provide a fail 
safe mode in case of power failure consistent with one 
or more of the preceding objects.

It is a further object of the invention to augment 
blood flow by application of counterpulse over a larger 
portion of the circulatory cycle compared to prior art 
systems consistent with one or more of the preceding 
objects.

SUMMARY OF THE INVENTION

According to the present invention, diastolic aug-
mentation is provided by a series of non-distensible 
bladders which are arrayed along the length of one or 
more limbs, preferably both legs of a patient, and si-
multaneously or sequentially pressurized to a range of 
about 2-6 psi while reacting against a surrounding hard 
casing providing a reaction force therefor. The casing 
is selectively hardenable or relaxable and comprises a 
filling of irregular particles which will lock together to 
harden when a vacuum is drawn on the casing and will 
separate and give the casing flexibility when the vac-
uum is released. The casing as a whole has a very low 
real and apparent weight and its synthetic hardenability 
allows effective operation of the bladders at the rela-
tively modest pressurization levels indicated above.

The casing is mounted on a support, preferably a ta-
tle. The apparatus preferably comprises a pair of com-
bination casing blanket/bladder arrays, as described 
above, constituting a set of pants mounted on a table in 
a chaps-like arrangement. The blanket/bladder ar-
rays can be spread out to allow the patient to sit down 
with his legs stretched across the arrays and then the 
blanket/bladder arrays can be wrapped around his legs 
and the wrapped legs can be strapped to the table. A 
bolster is provided to maintain the patient in a sitting 
position during operation of the equipment, both for 
his comfort and to combat reaction forces induced by 
pressurization of the pants which would otherwise tend 
to force the patient out of the pants. The bladders are 
filled with fully reticulated foam. This, together with 
their short longitudinal lengths, minimizes the possibil-
ity of inducing bubble blowing in the femoral arteries 
or other adverse effects of entrapment of air in the 
bladders themselves. The bladders have multiple gas 
access ports to further preclude blockage of air flow 
therein. The casings are segmented to prevent the par-
ticular material therein from shifting along length or 
width dimensions of the casings and comprise air per-
meable dividers therein.

After a patient is seated on the table or properly 
aligned with other support, the casing is partially hard-
ened by drawing a low vacuum thereon to partially lock 
the particulate material therein and thereby partially 
harden the casing. The partially hardened casing is 
wrapped around the patient's limb(s) with the casing 
surrounding the bladder array. A higher vacuum is then 
drawn on the casing to increase the rigidity and make it 
suitable as a reaction member. The casing is main-
tained in this condition throughout the course of treat-
ment which may be a session of as little as five minutes 
or up to several hours or round the clock diastolic aug-
mentation treatment. A bladder pressurization system
comprises a recirculating loop gas handling system of an air pump with an outlet connected to a pressure tank which is, in turn connected in successive flow sequence to a meter tank, a manifold which accesses the bladders via a series of throttle valves, a vacuum tank and the pump inlet. The loop also comprises appropriate valving to establish a subatmospheric pressure in the bladders by vacuum pumping via the manifolds alternating cyclically with superatmospheric pressure at the modest levels indicated above by rapid admission of pressurization charges from the metering tank which is itself recharged from the pressure tank (or in some systems recharged directly from the pump) between release of its charges to the manifold.

When the bladders are to be sequentially pressurized, the throttle valves of the manifold are adjusted to progressively narrower openings to define a series of pressurization rates in the sequence of bladders. However, the deflation, additional passage area is made available to all the metering valves so that all of the bladders can be deflated very rapidly with less differential in their deflation rates than in their respective inflation rates.

The admission of pressure charges from the meter tank to the manifold is synchronized with the patient’s electrocardiogram and the bladders are pressurized over some 50–70 percent of the period of the heartbeat. Admission of air into the manifold and inflation of the bladders is controlled to coincide with the beginning of diastole. The pressure in each bladder being pressurized rises rapidly, stays steady for a fixed period and then falls abruptly when the bladders are deflated. The system can operate with hearts which are beating very rapidly—as much as about 160 beats per minute, i.e., repeating its cycle almost three times per second.

Aside from controlling sequence of pressurization for peristaltic pumping, the valves are adjustable to provide uniform adjustment in all bladders of the inflation rate to fit the needs of different patients.

These and other objects, features and advantages of the invention will be apparent from the following detailed description with reference therein to the accompanying drawings in which:

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is an isometric view of the diastolic augmentation apparatus according to a preferred embodiment of the invention;

FIG. 2 is a partial cross-section view of a portion of the casing blanket/bladder array assembly used in the FIG. 1 apparatus;

FIG. 3 is a plane view of the bladder array/casing blanket assembly used in FIG. 1 in its unwrapped position and FIG. 3A is an exploded isometric view of the bladder air inlet/outlet fitting;

FIG. 4 is a schematic cross-section representation of the bladder air distribution manifold and single exemplary metering valve therein;

FIG. 5 is a cross-section view of a portion of the metering valve in a second position of operation compared to the first position shown in FIG. 4 therefor;

FIG. 6 is a mechanical block diagram of the pressurizing system for bladder inflation and deflation;

FIG. 7 is an electronic block diagram of calibrating controls for bladder inflation;

FIG. 8 is a display of panel control buttons showing control functions of the FIGS. 6 and 7 apparatus;

FIG. 9 is a block diagram of a bladder monitoring portion; subdivided into multiple channels, of the FIGS. 6 and 7 apparatus;

FIGS. 10 and 11 are oscilloscope traces of proper and improper sequence of inflation, respectively, of bladders using the FIGS. 6–7 apparatus; and

FIG. 12 is a graph sketch showing qualitatively the relation of electrocardiogram measured systolic and diastolic flow, assumed arterial pressure and bladder pressurization.

**DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS**

Referring now to FIG. 1 there is shown a diastolic augmentation pressuring apparatus in the form of a pair of pants 10 supported on a base such as a table 12, having a back 14 to enable the patient whose legs are wrapped in the pants to sit up. The table carries a control electronic console 16 and air pumping apparatus (not shown). The pants comprise, in each leg, a casing blanket 18 overwrapping a length series of bladders 20 which are wrapped around the leg(s). Metal tube piping 22 connects the casing to the vacuum pumping apparatus therefor through redundant connections to guard against blockage. Pipes 24 direct air flow to and from the respective bladders under the control of metering valves 26, described in greater detail below and which are adjustable through lead screw hand setting knobs 28. A transducer 24a is connected to the downstream (when pressurizing) side of each valve 26 to measure pressure in the bladder pair associated with the valve. Straps 30 secure the wrapped casing blanket/bladder array assembly around the patient’s legs.

Referring now to FIG. 2, there is shown a cross-section view of a portion of the casing blanket/bladder array assembly, this section being longitudinal. The overwrapping blanket casing 18 comprises two layers of fabric 32, both layers being air permeable. The blanket is subdivided into sections by dividing walls 34 which are air permeable. Each such section is filled with a particulated material 36 which may be sand, clay pellets, plastic pellets or metal particles or other irregular shapes, preferably heterogeneous sized. The sectioned construction 32, 34, 36 prevents the particles’ shifting or settling in a single region of the blanket. The blanket is covered by two layers of air impermeable material 44 and 46 which completely seal it from the atmosphere. The bladder arrays 20 comprises air impermeable plastic films 38 forming inner and outer and longitudinally segmenting walls to subdivide the bladders into longitudinal compartments which contain particulated foam 40. A disposable liner 42 for placing between the patient’s legs and bladder array 20 complete the assembly to be secured by holding strap 30.

Referring now to FIG. 3, the blanket/bladder array assembly is shown in unwrapped arrangement with portions broken away for convenience of illustration. The blanket 18 comprises holes 22a for mating with the pipes (22, FIG. 1) which evacuate or relieve vacuum in the casing to establish rigidity therein. There are five pairs of bladders 20 and each bladder has an inlet/outlet port defining assembly 24a. In FIG. 3, the port 24a is at the bottom of the bladder and has a fitting passing through the blanket. The viewing of the inlet port defining assembly 24a through the top layer of film of each bladder is artificially done for purposes of illustra-
tion only. In practice, the inner port would be obscured by the reticulated foam described above.

FIG. 3A shows in isometric exploded form, the inlet port defining assembly 24a comprising a tube 24b which defines an end connection to a tube 24 (FIG. 1). FIG. 3) passes through a hole in a layer of the blanket casing, a collar 24c securing the inlet port against the film to prevent leakage through the hole accommodating tube 24b, and an overlying fitting 24d having relieved portions 24e defining multiple ports around the circumference of the fitting 24d so that occasional blockage of one such port will not completely cut off access to the interior of the bladder.

Referring now to FIGS. 4 and 5, the air flow arrangement through the manifold and to the bladders is exemplified for a single pair of bladders. The manifold 25 has a pressure port 25a and a vacuum port 25b and a multiplicity of metering valves 26 therein, one of which is shown. Each such valve has a pair of ports 24f for accessing left and right leg bladders of a bladder pair via tubes 24 (FIG. 1) and a transducer 24g for measuring pressure in the bladder pair. A valving member 31 is adjustable by a lead screw 28 to vary the size of annular passage 33 thereby determining the rate of inflation or deflation of the bladders controlled by the valving member. A number of orifices 35 pass through the head of the valving member but are normally blocked during pressurization by a washer 37 secured to the valving member by a screw 39 and butting up against the valve member to shut off the holes 35. During deflation of the bladder, the washer droops away from the holes 35 as shown in FIG. 5 to clear the holes for increasing passage area for evacuation by some 100–200 percent depending on the size of holes 38 in relation to passage 33.

FIG. 6 shows diagrammatically the inflation/deflation gas handling system for bladders 20 and hardening system for blanket casing 18. The bladder system comprises a pump 50, a pressure tank 52, a metering tank 54, the manifold 25 and a vacuum tank 56 arranged in a closed loop with normally closed control valves 58, 59 and 62. Relief valves 64 and 66 respectively set maximum pressure in tank 52 and minimum pressure in tank 56. The blanket casing hardening system comprises a vacuum pump 60 connected to casing 18 via a normally open fail safe valve 63. An additional load can be imposed on pump 60 via a solenoid operated valve 67 and a vacuum relief 69. A pressure switch 68 senses vacuum level in casing 18 for purposes described below.

FIG. 7 shows the electronic control 16 (FIG. 1) in block diagram form including an electrocardiogram input signal amplifier 72, timing and control circuit 74, set up controls and monitoring fault indicator circuit 76 and interval control setting circuit 78. The circuits 76 and 78 are connected to operating solenoids or other relay drives for valves 58, 59, 61, 62, 63, and 67 and to pressure switch 68 as indicated.

Details of the circuits are omitted here as they will be apparent to those skilled in the art using conventional control circuits to achieve the control functions indicated herein.

FIG. 8 shows the start-stop controls for various stages of processing with legends as follows:
The Cycle On and Cycle Off switches start and stop the inflation-deflation cycle, and the Cycle Off switch also causes pressurizing of the casing.

The standby switch permits one to halt the bladder inflation-deflation cycle without repressurizing the casing. The Standby switch also allows vacuum to be drawn on the casing.

The Ready light indicates that the casing is properly depressurized.

The Lo Vac switch controls the application of partial vacuum to the casing. H.

The Hi Vac switch controls the application of harder vacuum to the casing.

FIG. 9 shows the calibration electronics using the transducers 24g of the five manifold valves 26 (FIGS. 1 and 4) connected, via five respective channels of amplifier A, level detector 24h, differentiator 24i and attenuator 24j, to a common summing amplifier 24k and an oscilloscope 24l. Waveforms generated in circuits 24a, 24d and 24f are indicated in FIG. 9. FIGS. 10 and 11 shows summing amplifier traces for proper and improper sequence of inflation of five bladders from ankle to hips (when peristaltic pumping is desired). The spikes are not pressure amplitudes per se but rather show that the measured pressure has exceeded a previously established baseline.

The spikes appear on the scope in the sequence in which the arrayed pairs of bladders fill. If a pair of bladders fills out of sequence, the ramp-like character of the display changes. For example, if the third pair of bladders fills before the second, the spike second from the left on the scope will be larger than the third from the left. The operator can then adjust orifice sizes in the metering valves to speed up the filling of the second pair of bladders or to slow down the filling of the third. In any case, this type of display serves to indicate the filling sequence is or is not correct and to identify which pair(s) of bladders is (are) out of sequence.

FIG. 12 shows qualitatively the approximate interrelation of electrocardiogram (ECG) arterial pressure in the aorta and bladder(s) pressure on a common time cycle base.

The arterial pressure trace P', T', Q' indicates cardiovular function without modification and P', T', Q'' indicates the nature of the modification to be effected by the apparatus.

The external cardiac assist apparatus is synchronized with the ECG by detecting the R-wave, and introducing a delay such that the pressure pulse in the external assist device, starts at the time the valve from the left ventricle to the aorta, the aortic valve, closes. The valve closes prior to the peak of the T wave which is at about the beginning of the diastole or at the point of the diastolic notch DN in the aortic pressure wave. The pressures in the bladders rise from a level A to a level B in a time of between 50 and 100 milliseconds with the pressure in the first bladder rising to its peak first, followed by the second, etc. as indicated by the transistions B1, B2, B3, B4, B5. The duration of pressure pulse in the bladder is adjustable and is set as a percentage of the heart beat cycle. For this, the interval between R-waves is stored and used as a time base. The deflation transition is indicated at B1.

A unique advantage of the external counterpulsation timing system is the capability to adjust the time at which bladder deflation occurs as a percentage of the time between R-waves. This method optimizes the assist interval by compensating for varying heart rates. Setting the beginning of deflation slightly before the R-wave precludes the possibility of residual gas pressure...
in the bladders causing some resistance to the contracting ventricle; thereby increasing the work load on the heart.

**OPERATION**

At the start of operation, the Power On/Off switch is activated to an On position to energize the electronics, start pump 50 and pump 50. Activation of the Standby switch closes the normally open manifold vent valve 61 and the normally open fail safe casing vent valve 63. When open, these valves connect the bladders and the casing to the atmosphere. The pressure switch 68 is in a position or state which inhibits opening of valves 58, 59, and 62. The bladders are wrapped about the patient's legs and hips and the casing 18 is positioned about the bladders and around the legs and hips. To facilitate the positioning of the casing, a partial or small vacuum is applied to the pants. When the Lo Vac switch on the console is pressed, valve 67 opens, pump 60 draws air from the casing past the pressure switch 68 and valve 63 and also some air from the atmosphere through the vacuum relief valve 69. Because air is being drawn through the valve 69, the pressure in the casing is reduced only enough to make it slightly rigid.

Pressure switch 68, which may be a bellows-type with an electrical contact, still inhibits the various valve drives. Switch 68 is adjustable to operate at various pressures and preferably is set to operate at 15 inches of mercury or half an atmosphere. This prevents pressure from being applied to the bladders before the casing becomes rigid. The application of pressure to the bladders without the casing surrounding and confining them could cause damage. When the casing is positioned satisfactorily, the Hi Vac switch on the console is pressed, and valve 67 is now shut to connect pump 60 directly to the casing. The casing is then pumped down to hard vacuum. When the pressure in the pants reaches 15 inches of mercury, the pressure switch 68 changes state which now permits the meter valve 58, pressure valve 59 and vacuum valve 62 to cycle. The Ready light on the console comes on. The vacuum pump continues to operate.

When the patient is ready and the pants are rigid, the Cycle On button on the console is pressed and the automatic sequence begins. The ECG signal is processed and the timing and control unit automatically tracks the R-wave and provides control signals to the various drive valves. Pump 50 which operates continuously, pressurizes tank 52 to a pressure controlled by valve 64, which is adjustable, and pumps out the tank 56 to a pressure controlled by the valve 66. The pressure set on the pressure relief valve and the relationship between the volumes of the pressure tank 52 (typically 7 gallons) and tank 54 (typically 2 gallons) determine the pressure in the tank 54 during operation assuming the pump is not overloaded. The volumes of the tanks are fixed so that regulating or changing the valve 64 regulates the pressure in the tank 54 and the pressure to which the bladders are pumped. Valves 64 and 66 are also safety valves. Valve 66 establishes a minimum pressure below which the pressure in tank 56 will not go. Another safety feature is that bladder inflation is initiated by the ECG so if the heart beat beat rate changes, the bladders will not inflate out of phase with the heart.

Prior to the beginning of the cycle, valves 58, 59 and 62 are closed; valve 59 is opened to start the cycle. The pressure in the tank 54 and in the bladders equalize with the pair of bladders furthest from the heart filling first, the adjacent pair filling next, and so on until the pair of bladders closest to the heart, that is, those about the hips, fill or inflate. Because the bladders fill sequentially, they exert pressure in a peristaltic manner on the legs. That is, pressure is applied to the ankle region first, then the calves, the knees, the thighs in turn and finally the hips. So long as valves 58 and 62 remain closed, the pressure remains steady and is exerted over the entire length of the leg, assuming that there are no leaks in the bladders or other parts of the system.

The length of time during which the pressure remains steady is adjustable (electronically) and is established as a percentage of the period between R-waves. To begin the deflation portion of the cycle, valve 59 is closed and valves 58 and 62 are opened connecting the tank 52 to the tank 54 and the bladders to the tank 56. The pressure in the bladders and the tank 56 equalize with the pressure in the bladders becoming about atmospheric or remaining a little above or falling a little below depending on the setting of the valve 66. At the time the bladders are deflating, the pressure in the tank 52 and that in the tank 54 are equalizing. After some small delay — some percentage of the heartbeat period — the bladder inflation cycle begins again.

If at any time during the cycle there is a power failure, manifold vent valve 61 opens connecting the bladders to the atmosphere, thus releasing any residual pressure, and pants vent valve 63 opens connecting the casing to the atmosphere thus causing them to soften. The patient would not be trapped in the pants or would pressure be exerted on his legs in the event of a power failure.

The various features and advantages of the invention are thought to be clear from the foregoing description. Various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims:

We claim:

1. Apparatus for external cardiac assistance comprising:
   - means defining a plurality of non-distensible gas fillable bladders which are wrapable about a human limb and unwrapable therefrom, said means including within said bladders compression preventing means for preventing complete local compression of opposing walls thereof at any point therein while allowing lateral gas flow;
   - means for selectively inflating and deflating said bladders by admission of gas and withdrawal of gas therefrom to selectively pressurize the cardiovascular system at the location in the limb wrapped by said bladders;
   - means defining a common casing blanket for overlying a series of bladder wrappings along a limb and being similarly wrapable about said limb and unwrappable therefrom along with said bladders; and
   - means for selectively hardening and softening the blanket casing comprising a filling of particulate material therein and means for drawing and releasing a vacuum therein to provide a substantially cylindrical reaction wall for the bladders and for soft-
ening the blanket casing to make it flexible for wrapping and unwrapping operations.
2. Apparatus in accordance with claim 1 wherein:
said compression preventing means comprise a bladder filling of fully reticulated foam.
3. Apparatus in accordance with claim 1 wherein:
said means for bladder pressurizing and depressurizing comprise means defining a manifold and metering valves therein associated with a series of said bladders,
the valves being separately adjustable to establish said sequential bladder inflation sequence and alternatively to establish a common adjustment of volume filled during inflation without movement of any parts during the inflation, and further comprising
means for increasing deflation flow rate comprise relation to inflation flow rate for all bladders.
4. Apparatus in accordance with claim 3 wherein:
said means for increasing deflation flow rate comprise passages through said valve means and flapper valve means thereon positioned to draw open under the influence of deflation suction.
5. Apparatus in accordance with claim 4 wherein:
said valves comprise a valving member moveable with respect to a valve seat to define an annular metering clearance therein,
means for adjusting the valving member/seat clearance from outside the manifold,
said passage means passing through said valving member and
said flapper valve means comprising a disk secured to a face said valving member away from said valve seat.
6. Apparatus in accordance with claim 3 and further comprising:
means for measuring pressurization of each bladder and temporal relation of pressurization of the various bladders.
7. Apparatus in accordance with claim 6 wherein:
means for synchronizing bladder inflation and deflation with a patient’s cardiovascular functioning to begin inflation essentially at the diastolic notch portion of the aortic pressure wave and complete deflation just prior to initiation of isometric contraction, and wherein:
said means for increasing deflation flow comprise passages through said valve means and flapper valve means thereon positioned to draw open under the influence of deflation suction,
said valves comprise a valving member moveable with a valve seat to define an annular metering clearance therein and comprising means for adjusting the valving member/seat clearance from outside the manifold,
said passage means pass through said valving member, and
said flapper valve means comprise a disk secured to a face said valving member away from said valve seat.
8. Apparatus in accordance with claim 1 wherein:
said means for pressurizing and depressurizing said bladders comprise
means defining a gas pump accessing each bladder through both a pump inlet at subatmospheric pressure and a pump outlet at superatmospheric pressure with a pressure tank and first valve between said outlet and bladders and a vacuum tank and second valve between said inlet and bladders and means for transferring a specific volume from said pressure tank to said bladders during inflation and from said bladders to said vacuum tank during deflation.
9. Apparatus in accordance with claim 8 wherein:
said means for transferring a specific volume comprise means defining a metering tank in line between said pressure tank and bladder.
10. Apparatus in accordance with claim 9 wherein:
said means for pressurizing and depressurizing said bladders further comprise a manifold and third valve means interconnecting said bladders with said first and second valves, and further comprising:
means for increasing the rate of bladder deflation flow through said third valve in relation to the rate of bladder inflation flow therethrough.
11. Apparatus in accordance with claim 10 wherein:
said means for increasing deflation flow comprise passages through said third valve and flapper valve means positioned thereon to draw open under the influence of deflation suction,
said third valve comprises a valving member moveable with respect to a valve seat to define an annular metering clearance therein and also comprises means for adjusting the valving member/seat clearance from outside the manifold,
said passage means pass through said valving member,
said flapper valve means comprise a disk secured to face said valving member away from said valve seat,
said blanket and bladders are in a preassembled form as a pair of pants in chaps arrangement with an array of bladders along each leg, and
said means for selectively hardening and softening said blanket casing comprise a filling of particulate material therein and gas pump means separate from said bladder pressurizing gas pump means for drawing at least two distinct levels of vacuum in said casing, and further comprising:
means defining a supporting table for said pants and a backrest and pants securing means on said table, interlock means preventing bladder pressurization until said pants are hardened, and
means for synchronizing bladder inflation and deflation with a patient’s cardiovascular functioning to begin inflation essentially at the diastolic notch portion of the aortic pressure wave and complete deflation just prior to initiation of isometric contraction.
12. Apparatus in accordance with claim 11 and further comprising:
a plurality of said third valves accessing separate bladders and having different gas flow rates for inflation but essentially equal gas flow rates for deflation and a plurality of bladder pressure monitors, means for displaying the inflation sequence of said bladders in response to signals from said bladder pressure monitors, and
means for individually adjusting said inflation flow rates.
UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO.: 3,866,604
DATED: February 18, 1975
INVENTOR(S): Richard W. Curless, Armando Federico, Alfred E. Magro and Michael L. Rishton

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 9, after "easily" insert--applied--; Column 1, line 19, for "suface" read--surface--; Column 1, line 27, for "apparati" read--apparatus--; Column 1, line 36, after "Proceedings," delete--have--; Column 3, line 19, for "the" read--for--; Column 5, line 48, after "relief" insert--valve--; Column 6, line 8, delete "H,"; Column 6, line 33, after "indicate" insert--if--; Column 8, line 48, for "about" read--about--; Column 9, line 17, for "comprise" read--in--; Column 9, line 36, for "comprising" read--comprising--; Column 9, line 40, for "furhter" read--further--; Column 9, line 52, delete "vlavingmembemoveable" and insert--valving member moveable--; Column 9, line 52, after "with" insert--respect--; Column 9, line 53, delete--valving member moveable--; Column 10, line 2, for "firt" read--first--; Column 10, line 2, for "betwen" read--between--; and Column 10, line 56, for "furhter" read--further--.

Signed and Sealed this
twenty-fifth Day of November 1975

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks