The Roller Pump Does Produce Pulsatile Flow

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Abstract

***(J. Extra-Corpor. Technol.* 19[3] p. 376–383 Fall 1987, 15 ref.) This study was undertaken to investigate, under experimental conditions, the nature of the roller pump output. Pressure and flow studies were done on 200° roller pumps using PVC and silastic formulations in the raceway. Polyvinyl chloride (PVC) tubing in all sizes produced comparatively higher pressure levels with narrow pressure spikes. Small bore tubing with high revolutions per minute (RPMs) delivered characteristic pulseless flow due to telescoping of flow and pressure pulses. Large bore PVC tubing produced pulsatile flow curves with spikes, ripples and artifacts. Silastic and fluorocarbon tubing achieves pulsatile flow curves without ripples or artifacts at a comparatively lower pressure range. A wide pulse width and a single roller ripple chararacterize it. Ideal combinations used clinically in over 1,500 cases result in appreciable pulse flow measurable in significant changes in renal output both in normothermic and hypothermic conditions.**

These results show that a regular roller pump, with the use of tubing with specific viscoelastic properties and the proper choice of stroke volume, will produce a significant level of pulsatile flow. There is no need for an add-on system. Preliminary work utilizing a single roller pump, as a means of enhancing the pulse wave, is presented. Techniques to remove the 200° single roller induced ripple is also discussed.

Introduction

It was established that the roller pump did produce pulsatile flow.[1] Recently this has been confirmed by other investigators.[2,3] Many others have claimed consistently that the roller pump produced only pulseless flow.[4,5] If the pump did produce pulsatile flow, but nonpulsatile flow was delivered to the patient,[3] efforts had not been taken to enhance the pulse wave and make it available to the patient. We have resorted to ingenious, expensive and frustrating pieces of add-on equipment to reproduce that which was lost in transit from the pumping head to the patient. Many authors believe[6,7,8] that if only an easier and inexpensive means were available, pulsatile flow would be practiced by a greater cross section of the perfusion community.

Over a period of years we have studied the problem, both experimentally and clinically, to understand the basics of pump performance, to preserve the pulse produced and even enhance it, if possible. It is our understanding that it is possible for most of us to achieve a meaningful level of pulsatile flow with the regular roller pump we use every day. Having achieved this clinically ourselves, we are acting further to enhance it, so that a true ripple and artifact free pulsatile flow can be achieved in the roller pump without all the expenses and complications of the presently practiced pulsatile flow technology.

Materials and Methods

An experimental circuit (Figure 1) was designed to study pressure and flow data. Sarns, Stockert, and Pemco design roller pumps were used in this study period. PVC, Silastic, Silastic R and Fluorocarbon tubing of different diameters were tested in the raceway. Pressure and flow probes were mounted within 3 inches of the output side of the rollers. Statham Gould pressure and flow transducers were used with regular physiological monitors to monitor and record data.

The experiment was done in 3 groups. The first 2 groups were in vitro evaluations. Group I was designed to test the effect of the rollers on the tubing materials in its effort to pump. It was performed to confirm data

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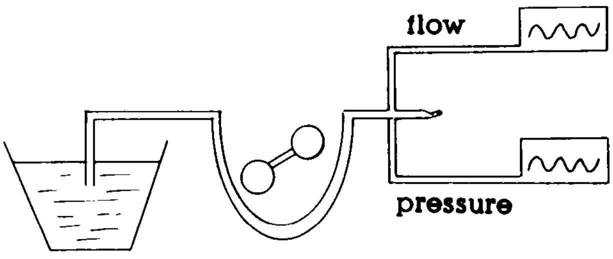

GROUP 2

Figure 1: Flow and pressure were measured 3" beyond the output end of the roller pump. The outlet end was either an 8mm Sarns soft tip catheter or a 24 Fr. USCI catheter open to air.

already reported regarding the production of low amplitude and high frequency pulses.[3] Pressure, volume, and RPMs were interrelated, confirming the ripple flow effect. The output end contained our regular arterial cannula, which is either the 8mm Sarns plastic catheter or a 24 French USCI catheter.

The third group was made up of the clinical work conducted at 2 different institutions following the same techniques; one institution used only bubble oxygenators, and the other used only membrane oxygenators. Both groups worked with a variety of pumps and oxygenators. The comparative data of one group of this technique with the state of the art Cobe Stockert pulsatile flow system is also discussed.

Results

In group I, the pressure and flow produced in standard ⅜ inch I.D., PVC, and silastic formulations (Figure 2) indicate that at lower RPMs, the flow and pressure were comparable. At less than 2,500 cc flow for both tubing, which would be less than 100 RPMs, a significant pressure difference begins to present itself. The PVC compounds generated a higher pressure than the silastic formulations. With use of the widest size in the raceway, the same situation was studied (Figure 3). Once again, PVC tubing generated a higher level of pressure to propel the same volume, though at a lower RPM. The fact that at lower flow rates the diastolic pressure returned to 0 indicated the pulsatile nature of the flow. The development of a diastolic pressure at a higher flow rate indicated that the flow and pressure pulses were piling upon each other due to the nonavailabilility of the diastolic run-off time.

The results of testing PVC tubing of different diameters indicated to us that PVC tubing in all sizes had the same type of pulse production, narrow pulses with high pressure spikes (Figures 4 and 5). Since the pulses did not have any pulse width, their effect on the arterial system could be only imagined. Further tests with

⅜" I.D. 3/32" W.T. Tubing			
Fluoro		PVC	
Pressure	Flow	Flow	Pressure
157/0	1300 cc	1200 cc	156/0
197/0	1560 cc	1500 cc	199/0
243/0	1820 cc	1800 cc	246/0
356/0	2340 cc	2400 cc	395/0

Figure 2: Pressure and flow relation in PVC and Fluorocarbon tubing.

⅝" I.D. Fluoro 60 cc/rev		Flow	⅝" I.D. PVC 77 cc/rev	
Pressure	RPM	L/min	RPM	Pressure
0/0	16	1	14	0/0
36/0	33	2	29	42/0
58/0	50	3	43	55/0
87/14	66	4	57	121/33
135/56	83	5	71	170/64
196/100	100	6	86	275/113

Figure 3: Pressure and flow relation in PVC and Fluorocarbon tubing of wide bore (⅝" I.D.).

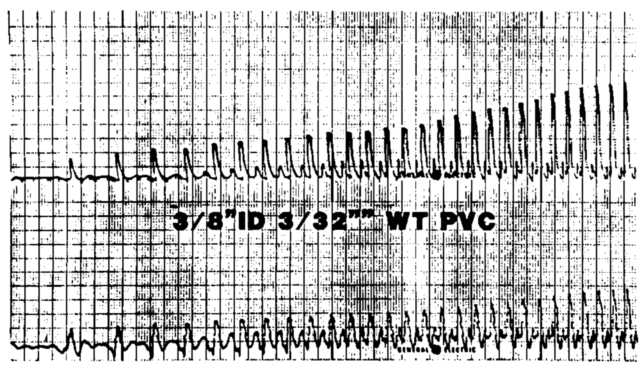

Figure 4: Narrow rapid pressure spikes produced in standard ⅜" PVC tubing.

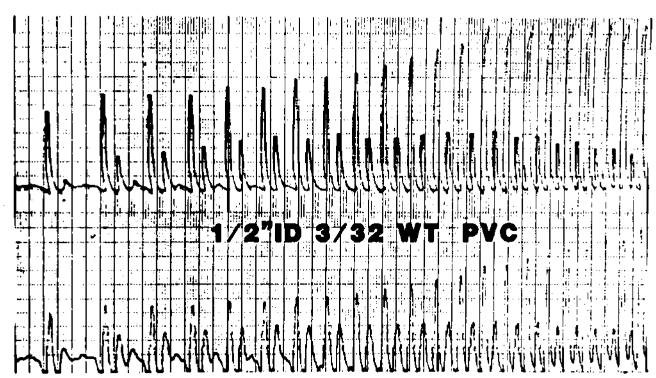

Figure 5: Other sizes of tubing in PVC also tend to produce the same type pressure spikes.

the most widely used tubing in the raceway, the 3/8 inch I.D. tubing (Figure 6), produced such rapid and narrow pulses that they were hardly visible. In an adult clinical setting it would be necessary to give as much as 200 RPMs to propel 5 L/minute and the corresponding 400 or more strokes per minute pulses will be completely damped presenting the commonly seen (Figure 7) pulseless flow pattern clinically. This has been reported previously.[3] Since it was already established by Ankeney et al in 1969[9] and others[10] that wider tubing sizes in the raceway permitted higher flows with lesser RPMs and therefore less trauma, it was decided to use only larger tubing for the final batch of tests.

In group II, tests were done on 5/8 inch PVC and fluorocarbon tubing with simultaneous pressure and flow evaluation. PVC tubing from as low as 30 RPMs started developing artifacts (Figure 8), which increased in intensity and number as the flow was increased to 40 RPMs (Figure 9). As the flow increased to 50 RPMs (Figure 10), there were positive and negative ripples and artifacts in every pulse, which were totally nonindicated in the pressure curve. Since 50 RPMs in 5/8 inch tubing would barely come close to 4 L/minute flow, one can only imagine the ripples, artifacts, and erratic flow that would be produced when such tubing is used for adult clinical situations.

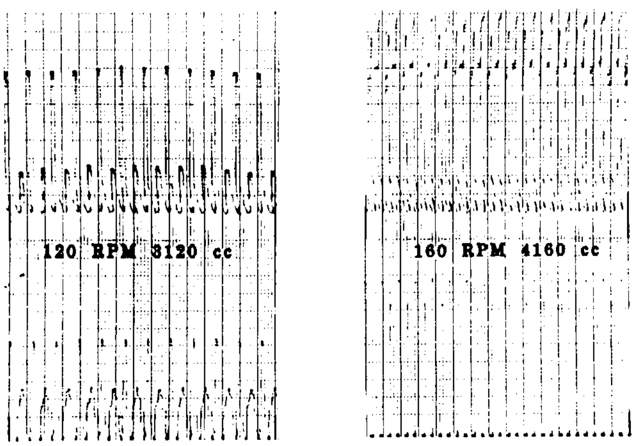

Figure 6: The high rate of pulses produced and the narrow pulse width in standard 3/8" I.D. PVC tubing at 120 and 160 RPMs.

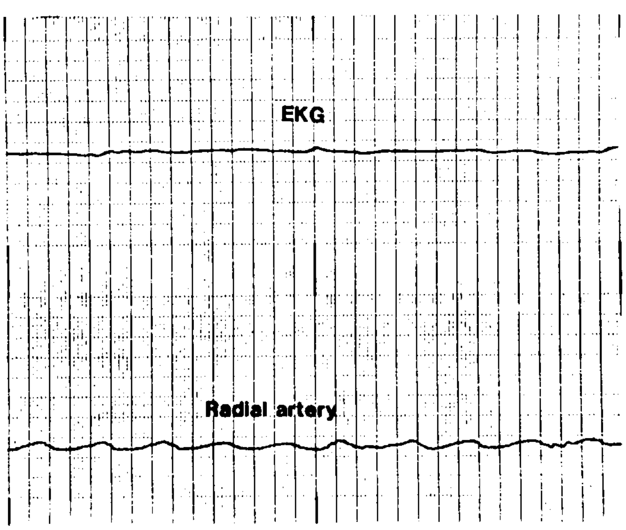

Figure 7: The normal pulseless arterial pressure tracing that is usually seen.

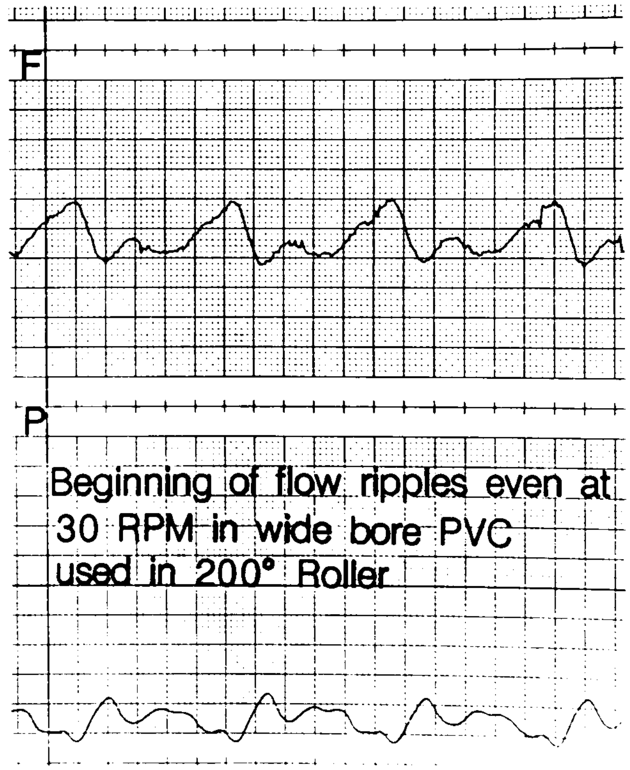

Figure 8: Flow and pressure curves in PVC tubing in 200° roller pump indicate pulsatile flow. The flow wave indicates the beginning of flow artifacts.

Since pulse flow is usually estimated by studying the arterial pressure tracing, all the artifacts that are produced clinically go completely unnoticed. We believe that a tubing that gives ripple and artifact free flow should be used in the raceway if good pulse flow is to be maintained.

The same study repeated with fluorocarbon tubing (Figure 11) yields almost distortion free pulsatile flow without artifacts. There is only one flow ripple that is induced by the roller and this is impossible to eliminate as long as one is using a 200° roller pump. The complete pulsatile nature can be assessed from the observation that at 6 L/minute flows both pressure and flow pulses return to the diastolic 0, proving that there is no residual flow buildup toward a diastolic pressure. We believe that the softening of the flow curve and the absence of artifacts and ripples is due to the viscoelastic properties of the fluorocarbon material.

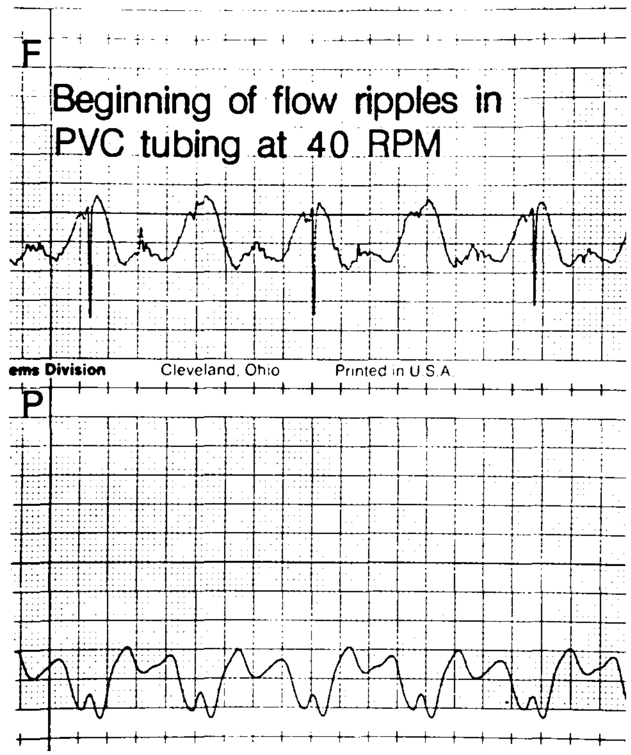

Figure 9: At increased flows, the artifacts increase in size and magnitude while no indication is seen in the pressure wave regarding the flow artifacts.

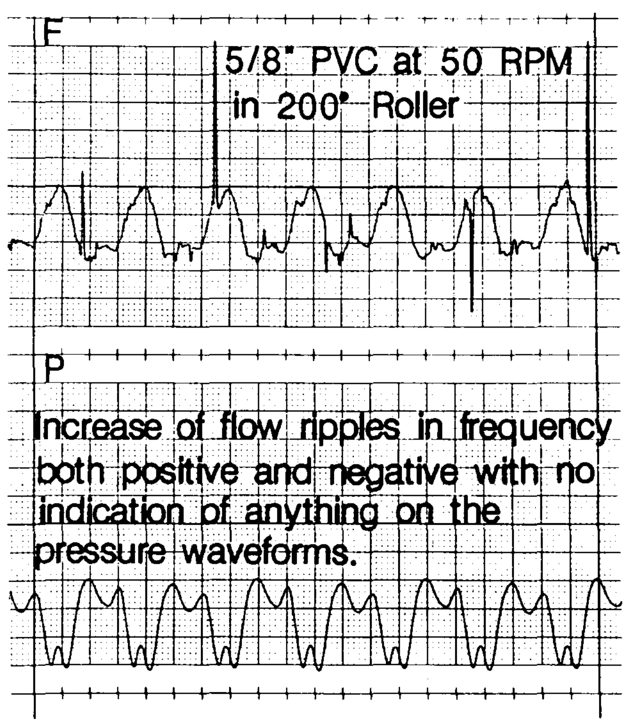

Figure 10: At 50 RPMs every flow wave generates artifacts and ripples though flow continues to be pulsatile.

6 L flow/minute
⅝° Fluorocarbon head width
8mm open tip
No flow till pressure peaks.

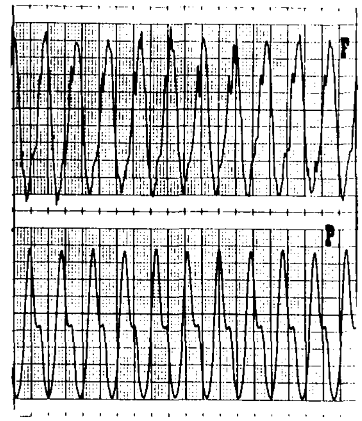

Figure 11: Fluorocarbon tubing exhibiting pulsatile flow with no flow artifacts and ripples.

The decision to use the fluorocarbon tubing clinically was made several years ago. Before it became available, Silastic and Silastic R tubing were used. Both of them correspondingly produced the same results as the fluorocarbon tubing. Our clinical experiences are from two different centers, one using bubble oxygenators and the other, membranes. Our review is from a total of clinical cases exceeding 1,500 to date.

Use of ⅝ inch fluorocarbon in the raceway for all adult perfusions produces pulse pressures, both in normothermic and hypothermic conditions (Figure 12). Depending on a variety of conditions, the pulse pressure can be anywhere from 10 mm to 40 mm and more. Our experiences cover patients from as little as 30 Kg up to 150 Kg in weight. We have been able to get good pulse pressures in patients up to 120 Kg. Heavier patients produce much less pulse pressures.

A comparison of the Cobe Stockert Pulsatile flow control unit in these situations confirms to us that there are only marginal differences between our techniques and the state-of-the-art system in terms of greater pulse pressure (Figure 13).

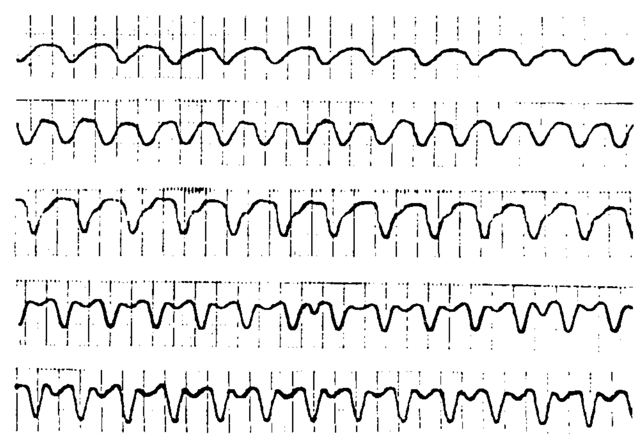

Figure 12: Graded types of pulse waves formed during clinical use of ⅝" pump heads, pulse pressures ranging from 5 to 40 mmHg. Taken from actual clinical cases.

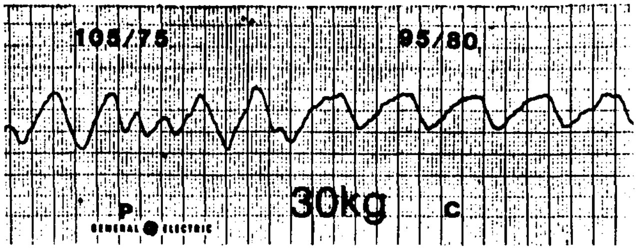

Figure 13A: Area marked "P" is pulsatile mode on the Cobe Stockert system and area marked "C" is on continuous mode. Small sized patient.

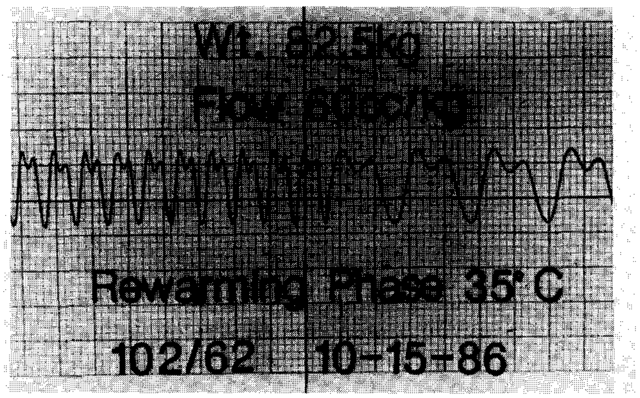

Figure 13B: Average adult in clinical setting achieving a pulse pressure of 40 mm without use of special pulsatile systems.

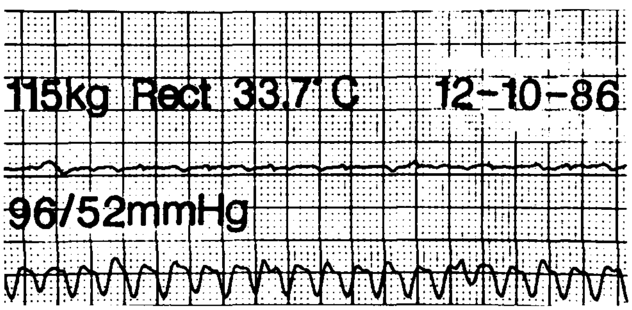

Figure 13C: Heavy patient weighing 115 Kg achieving a clinical pulse pressure of 44 mmHg.

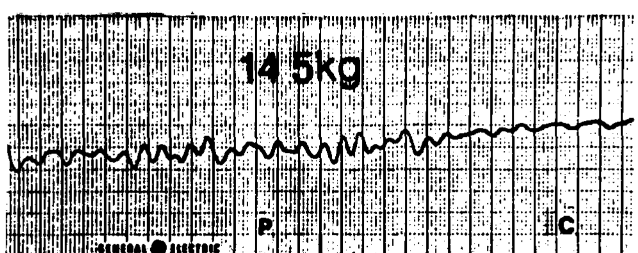

Figure 13D: A very heavy patient at 145 Kg being handled by the Cobe Stockert pulsatile flow system (P) and in continuous mode with almost same results. The difference in the pulse pressure produced is less than 5 mmHg.

The lightest patient and the heaviest one have comparison tracings with the Stockert unit on pulsatile mode and continuous mode. In either instance, the change in pulse pressure is between 5-10 mmHg only. We believe that a larger stroke volume may be needed to handle patients heavier than 120 Kg.

A comparative study was undertaken between our system and a completely pulseless system clinically (Figure 14). The regular roller pump and a Bio-Pump were connected in parallel and the effect of the pulseless flow and pulse flow were estimated from their effect on the renal output during 30-minute periods alternatively. The effect of pulsatile flow on the kidneys is sufficiently well documented[10,11,12,13,14] and lends support for this type of comparison, (Figure 15). The roller pump output was almost twice as much as that of the Bio-Pump in terms of renal flow for the same period of time, for the same rate of blood flow.

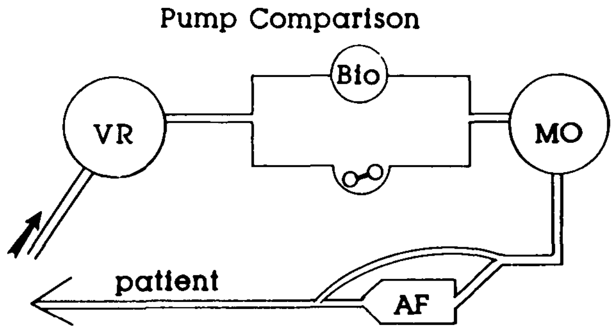

Figure 14: Two pumps used in parallel to study if effective pulsing is making any difference in the renal outputs.

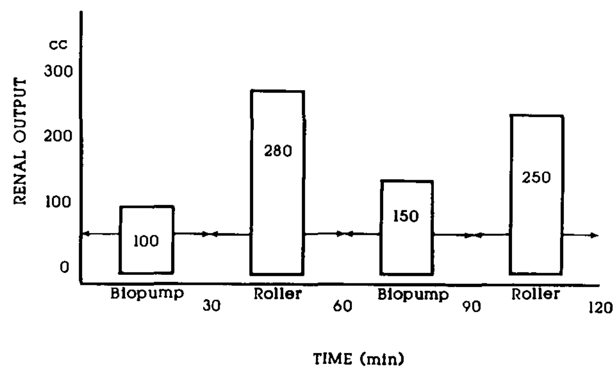

Figure 15: Consistently higher production of renal flow in the roller pump is attributed to the pulse output present in the system as against the flow obtained in the biomedicus pump which is known to be pulse free.

The effect of some membrane oxygenators to dampen pulsatile flow in the circuit is a recognized problem. In a recent comparison of 2 different membrane oxygenators (Figure 16), we found a marked difference in the renal output in one membrane oxygenator com-

AVERAGE	OXYGENATOR A	OXYGENATOR B
WT.	80.2 KG	77.8 KG
FLOW	62 CC/KG/MIN	66.5 CC/KG/MIN
BYPASS TIME	122 MIN.	115 MIN.
URINE OUTPUT	1,222.6 CC	592.2 CC
LASIX	11.6 MG	63.2 MG

25 PTS. IN EACH GROUP

Figure 16: Comparison of two membrane oxygenators in renal outputs study.

pared to the other for nearly the same controlled situations. Further investigations (Figure 17) proved to us that the drastic reduction in the renal output was related to the dampening of the pulse. As shown in the figure, membrane A attains a higher peak pulse pressure, maintains this pressure, and allows the diastolic pressure to return to baseline. Membrane B achieves only a pulse pressure that is 20% less than membrane A. It does not sustain this pressure consistently and does not allow the diastolic pressure to return to baseline. This dampening effect would account for the difference in renal output.

While a satisfactory pulse pressure is thus being produced in the roller pump and preserved until it reaches the patient, our efforts now are directed toward further enhancing the pulse flow to the point of increasing the pulse pressure (as a means of handling heavier patients) as well as reducing the ripples that are produced. Many ripples are produced in the commercially used units, and as we have noted, there is at least one ripple in our system. The presence of ripples are roller induced and cannot be removed except when a single roller is used.

That a 360° single roller produces better pulse flow than other rollers has been documented previously.[2,14] For the same size raceway, a single roller also has the ability to increase the stroke volume. With these in mind, a state-of-the-art 360° single roller pump was obtained from Ms. Polystan (Figure 18) and its output

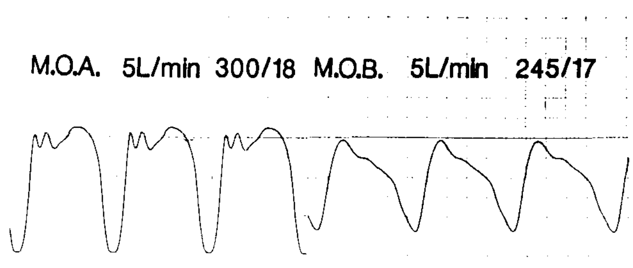

Figure 17: Comparison of pressure pulses produced by both oxygenators at the arterial filter site as an indication of sustained pulse in one and the dampening of it in the other.

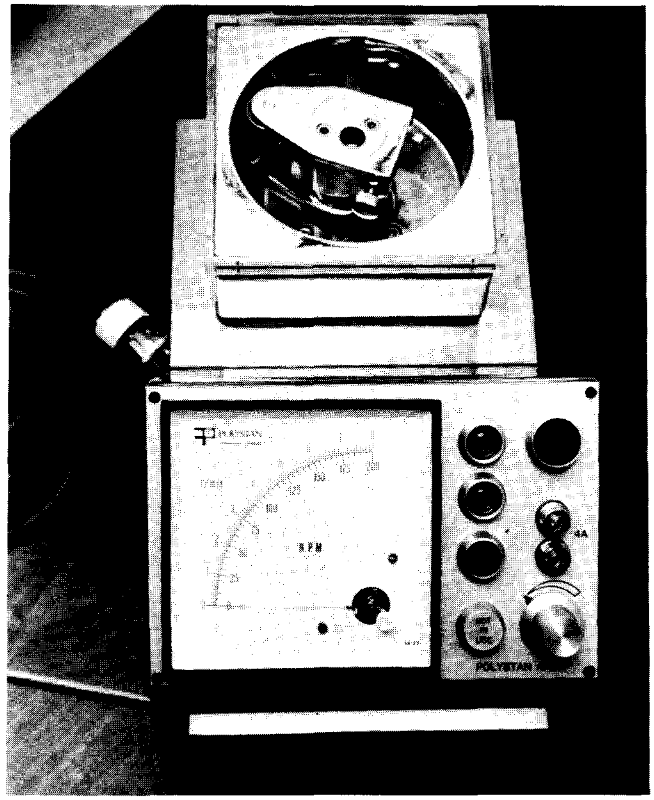

Figure 18: The single roller pump that is being tested for ripple-free pulsatile flow production clinically.

tested experimentally. From these investigations (Figure 19), we believe that a single 360° roller pump would be far superior used as a pulsatile pump than the existing 200° rollers, which will always present roller induced ripples, in the pulsatile mode.

Analysis of the waveform in the single roller also permits us to believe that the ejection phase, the upstroke on pressure waveform, and the upstroke on flow wave-form are within acceptable limits as described elsewhere (Figure 20). The first half circle of the roller rotation from zero point produces the pressure cycle and the half relates to the time when the flow commences according to the simultaneous pressure flow tracing. Thus it would be a quite simple matter to decelerate, stop, and accelerate at the shaded portions, on either side of the 0 point, in order to use this pump for synchronizing with the EKG or arterial pressure for counter pulsation purposes. In this case, unlike 200° roller pumps, it would produce ripple free pulsatile flow. Work is progressing toward getting this technology to the clinical area.

Meanwhile, a national survey reveals the perfusionist's choice in the type and size of tubing they prefer in clinical work. While 75% prefer the PVC, only 25%

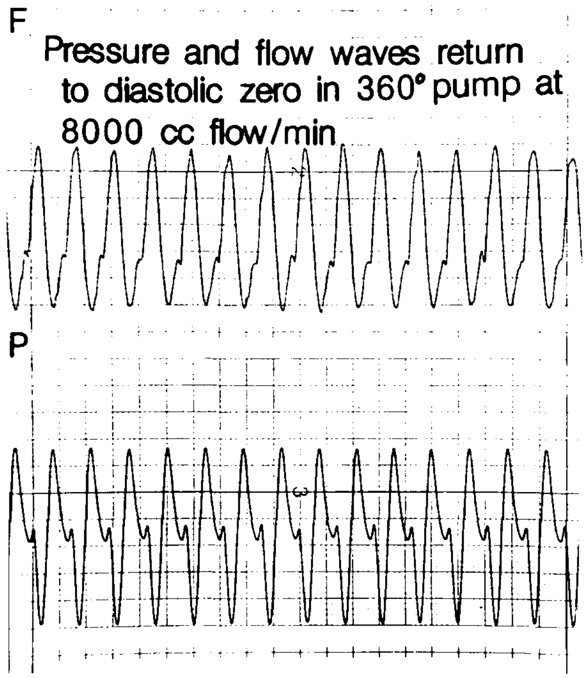

Figure 19: The flow and pressure waves produced at the pumping head in the single roller 360° roller pump confirms pulsatile output and the absence of ripples and artifacts.

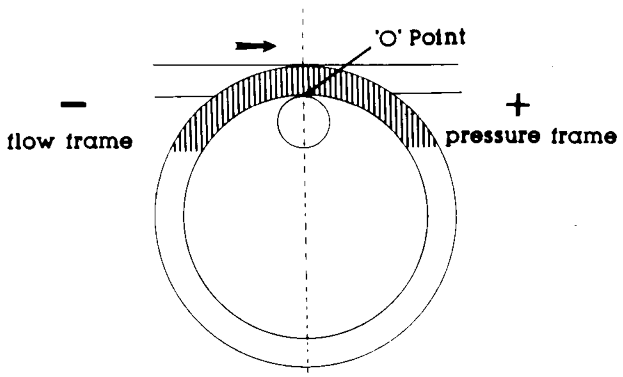

Figure 20: The theory to develop ripple-free pulsatile flow in roller pumps is by stopping the roller at the "0" point, accelerating and decelerating (if need be) at the immediate next areas on either side. The rest of the cycle is evenly shared by the pressure and flow cycles.

prefer using silastic or fluorocarbon tubing in the tubing in the raceway. With this type of tubing preference, 65% of all perfusionists use ⅜ inch I.D. tubing and this means that the majority of us are using PVC tubing at high RPMs, losing the pulse that the pump is capable of producing and delivering otherwise. Ideally, use of a ⅜ inch I.D., silastic or fluorocarbon tubing, should give good pulse flows up to a blood flow rate of 2 L/minute, ½ inch I.D., should give good pulse flows up to a blood flow rate of 3.5 L/minute, and ⅝ inch up to 6 L/minute.

Our work would clearly show that the roller pump does produce good pulse flows that can be available to every perfusionist, regardless of which type or make of roller pump being utilized. Adequate stroke volume for a given patient and the right type of viscoelastic properties in the raceway tubing are the only keys to providing pulsatile flow. With no more changes in the system, most of us can provide a meaningful pulsatile flow clinically every day. Further work on the single roller pump might bring in a comparatively cheaper method of achieving completely synchronized pulsatile flow system in the future, but that remains to be seen.

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Questions from the Audience

Question: Michael Hurdle, Indianapolis, IN: Do you believe that the positive effect of the pulsatile waveform produced with a larger bore silastic or latex tubing outweighs the negative effects that have been reported periodically of plasticisor leaching, and one thing and another from those more pliable materials?
Response: I have been using it long enough. I have not noticed any problems related to that. Does that answer your question?
Comment: Yes.
Question: Steve Murphy, Irvine, CA: Have you thought about the application to counterpulsation—how it will affect your flow and how it will affect your pump RPM to achieve a desired flow rate if you're trying to synchronize to a heart rate?
Response: Are you talking about a single roller pump?
Question: With your single roller pump. In other words, how do you achieve counterpulsation?
Response: Very simple. You use sufficiently large size tubing to give you the right stroke volume you need. And put it at a one to one ratio. That's it.
Question: If you're coming off bypass and you're synchronizing to the heart, you're not advocating changing the tubing, to change stroke volume during the procedure, are you?
Response: No.
Question: Joel Davis, South Bend, IN: I want to disagree a little bit on the fact that you can't get a reasonably good pulse pressure using a double roller pump. Use a high speed. You can get a waveform that is very similar to this. We presented this back in the Spring 1982 journal of AmSECT. But it is quite possible to minimize the artifact by using a single revolution technique for pulsing, and by using an adequate enough speed, the second roller compressing on the tubing is barely visible.
Comment: Steve Murphy, Irvine, CA: We've been using a double roller pump with ⅝-inch elastic tubing for about 25 years. You beat me to the punch on the paper.
Response: Thanks.