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VOLUMETRIC INFUSION PUMPS

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Summary

In intensive therapy, intravenous infusion of many solutions and drugs demands very accurate control. This can be achieved by volume delivery either with a piston type pump or by peristaltic pumping action on an accurately made tube of an administration set. Volumetric pumps are designed to overcome the limitations associated with variations in drop size. Recently, the number and variety of these devices has increased dramatically. Existing volumetric pumps are more expensive to operate than drop counting systems, but they are safe and accurate for the delivery of potent drugs to patients.

Introduction

The number and variety of infusion control devices has increased dramatically in the last few years. These devices encompass a large number of instruments such as pumps, controllers and syringe drivers with many uses (1).

Volumetric infusion pumps are used when the accuracy of the fluid volume to be infused is critical, for example, for administration of the potent short-acting drugs used for circulatory support. Unlike drop counting systems which measure the infusion rate in drops per minute and are therefore subject to inaccuracies caused by variations in drop size (2, 3, 4), volumetric pumps deliver a given volume of fluid per unit time (millilitres per hour). This study was undertaken to evaluate the operational characteristics of these volumetric devices.

Classification

Volumetric infusion pumps currently in use can be conveniently classified according to their mode of operation:

1. Linear peristaltic pumps

In these the fluid is propelled by the squeezing action of in line finger-like projections sequentially compressing the i.v. tubing against a stationary backing plate. As the external force moves along the deformable tubing, the fluid within is forced ahead of the external pressure and eventually delivered to the patient.

2. Rotary peristaltic pumps

These have rollers mounted on a wheel that compress the tubing and move a point of occlusion towards the patient. Pumping takes place when the tubing of the infusion set is compressed by one of the rollers. The infusion rate is controlled by varying the speed of the rollers.

3. Reciprocating piston pumps

A reciprocating piston moves in a disposable cylinder and a fixed volume of fluid is drawn into the cylinder and then pumped out at a selected rate. Either a rotary valve or an occlusion mechanism on the inlet and outlet tubes directs the flow depending on whether the piston/cylinder cassette is filling or expelling the solution.

4. Piston actuated diaphragm pumps

These also utilise disposable cassettes which have a fluid filled chamber with a flexible rubber diaphragm and one-way inlet and outlet valves. The pump mechanism pushes against the diaphragm displacing fluid in the chamber through the outlet valve to the patient, and then refills the chamber with a small amount of fresh solution from the i.v. container by releasing the diaphragm. This principle virtually eliminates the possibility of air being pumped to the patient.

Evaluation

Laboratory and clinical tests were carried out on 8 different volumetric infusion pumps (Table 1): two linear peristaltic pumps (Braun Infusomat Secura and Terumo Terufusion STC502), two rotary peristaltic pumps (Critikon Simplicity 2102A and Narco AS70), two reciprocating piston pumps (Imed 960 and Ivac Infu-Check 1500) and two piston actuated diaphragm pumps (Travenol Flo-Gard 8000 and Valleylab IV6000).

For each pump the features evaluated were:
Accuracy of infusion rate
Consistency of flow
*Reliability of alarm conditions
*Ease of clinical use.

Methods

The flow rate was measured in millilitres per hour by timed collections in a volumetric flask. Three separate measurements were made at each selected flow rate. For all tests

Table 1: A comparison of volumetric infusion pumps

Pump (Model)	Type	Range (ml/hr)	KVO Rate (ml/hr)	Weight (kg)	Dimensions WxHxD (mm)	UK Pump Price (£)	UK Infusion Set Price (£)	Manufacturer
Braun (Infusomat Secura)	Linear finger peristaltic	1-400	1	6.4	130x270x260	1238	1.55	B. Braun Melsungen AG P.O.B.110+120 D-3508 Melsungen West Germany
Terumo (Terufusion* STC502)	Linear finger peristaltic	1-299	1	4.0	95x235x145	950	1.25	Terumo Corporation 44-1, 2-Chome Hatagaya. Shibuya-Ku Tokyo, Japan
Critikon (Simplicity **2102A)**	Rotary roller peristaltic	1-999	3	4.54	180x200x150	850	2.71	Critikon Inc 1410 N. Westshore Boulevard, Tampa Florida 33607, USA
Narco **(AS70)**	Rotary roller peristaltic	0.1-499.9	1 or less	4.5	191x254x229	1650	5.02	Air-Shields Harboro Pennsylvania 19040 USA
Imed (960)	Reciprocating piston syringe cassette	1-999	1	7.36	276x286x138	1260	2.75	Imed Corporation - 9925 Carroll Canyon Road San Diego CA 92131 USA
Ivac (Infu-Check **1500)**	Reciprocating piston syringe cassette	1-999	5 or less	5.0	105x343x187	1095	3.50	Ivac Corporation San Diego California USA
Travenol (Flo-Gard **8000)**	Piston actuated diaphragm cassette	1-999	5 or less	5.5	200x300x200	1400	3.00	Travenol Laboratories Inc Deerfield Illinois 66015 USA
Valleylab **(1V6000)**	Piston actuated diaphragm cassette	1-499	1	4.2	150x236x223	1275	4.00	Valleylab 5920 Longbour Drive P.O. Box 9015 Boulder Colorado 80301, USA

**Terufusion STC502* has now *been superceded by STC5031 This* has *the same mechanical characteristics as STC502* but it has touch *controls instead of thumb wheels for rate and volume settings.*

ICW wishes to point out that prices can vary from country to country; prices quoted **are for guidance only.**

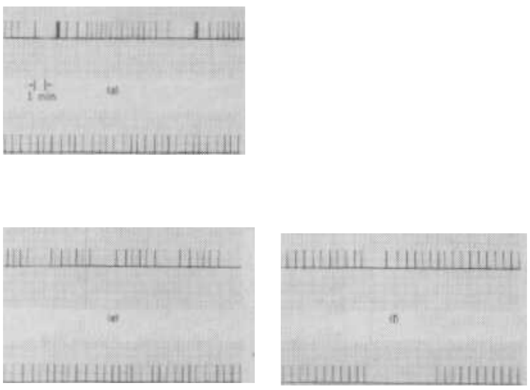

Figure 1: Drop pattern at 2 ml/hr for (a) Braun (b) Narco (c) Travenol (d) Critikon (e) Valleylab (f) Imed (g) Terumo, and (h) Ivac

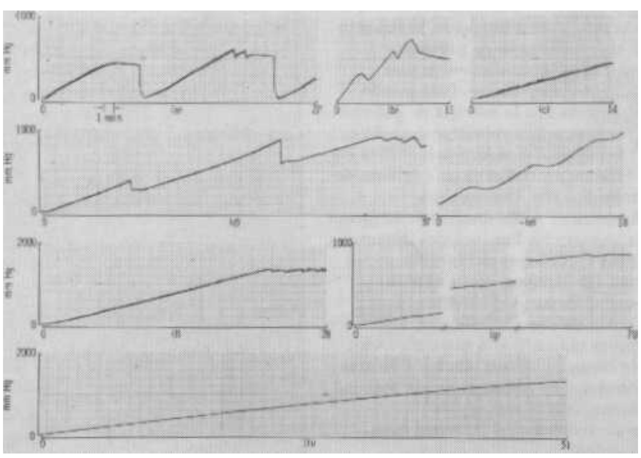

Figure 2: Continuous recording of pressure when the outlet was closed with a three-way tap, at infusion rate of 2 ml/hr for (a) Braun (b) Narco (c) Travenol (d) Critikon (e) Valleylab (1) Imed (g) Terumo, and (h) Ivac

the fluid used was 5% dextrose (Viaflex - Travenol Laboratories Ltd.).

Consistency of flow was measured at 2 ml/hour by passing the fluid through a 14G Vygon catheter and recording the pattern of drop delivery at the catheter tip using a photoelectric sensor; recordings were made on a constant speed chart recorder (Gould-Brush 220) (Fig. 1).

The back pressure alarms *were* provoked by closing the outlet of the delivery tube from the infusion pump using a three-way tap. The output pressures developed by the pumps were measured with an SE Laboratories transducer (SEM 4.86) and pressure converter (SE 905). The time required to reach the pressure that triggered the occlusion alarm was calculated from the recordings (Fig. 2) and the volume of fluid accumulated in the i.v. tubing was also measured.

On a more general investigational level, ease of setting up the instruments, priming and changing of disposables were examined by technicians and nurses.

Results

A brief description of each pump with its principles of operation is presented. The accuracy of infusion rate is expressed as a percentage error, that is the mean difference between the rate set on the pump and the actual rate measured. The reliability of the occlusion alarms is presented as the time taken for them to operate after the delivery tube has been completely occluded (Fig. 3). The findings are summarised in Table 2.

Linear Peristaltic Pumps

Braun Infusomat Secura (Fig. 4a)

This pump is driven by a stepping motor and uses a dedicated infusion set which includes a silicon rubber insert. The infusion rate entries are displayed as ml/hr by a large 3 digit LED display; the digital entry touch buttons are inoperative when the pump is running.

False alarms are common and can cause the average flow to be considerably less than expected. On several occasions during the test period the flow rate alarm was activated probably because of splashing onto the drip chamber wall preventing the sensor from detecting normal flow. It is possible to set rates higher than the 400 ml/hr maximum rate specified by the manufacturer but the pump would alarm if this rate were to be exceeded. At low flow rates, such as 2 ml/hr, the pump has an irregular pattern of delivery (Fig. 1a).

Terumo Terufusion STC502 (Fig. 4b)

This pump has 12 fingers driven by a stepping motor. Thumbwheel switches are used to set the volume and flow rate of the fluids to be infused and the total volume delivered is shown on an LED display panel. Four red alarm lights indicate low battery, air in line, occlusion and completion of infusion. There is one green light to warn whether the pump is running on battery or mains power.

This is a compact unit of small size and weight. The setting up procedure is simple, changing flow rates is easy, and the pump

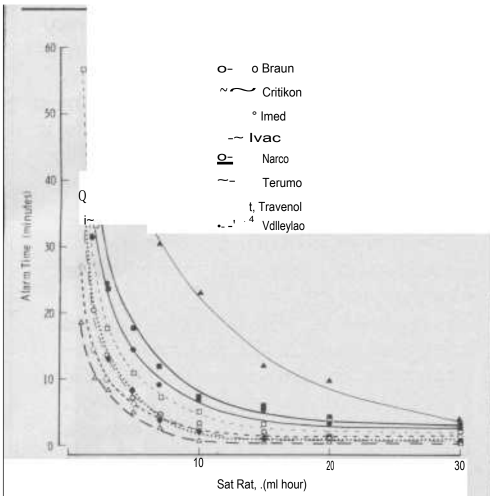

Figure 3: The relationship between set rate and alarm time when the outlet was closed with a three-way tap

Figure 4b: The Terumo Terufusion STC502 pump

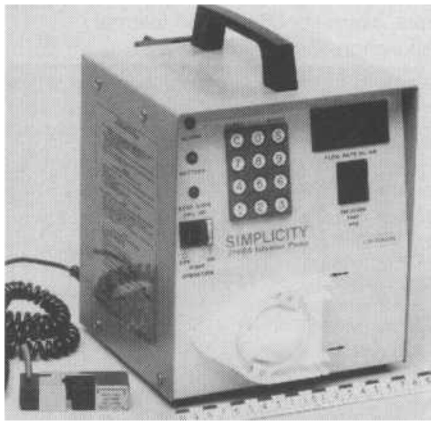

Figure 5a: The Critikon Simplicity 2102A pump

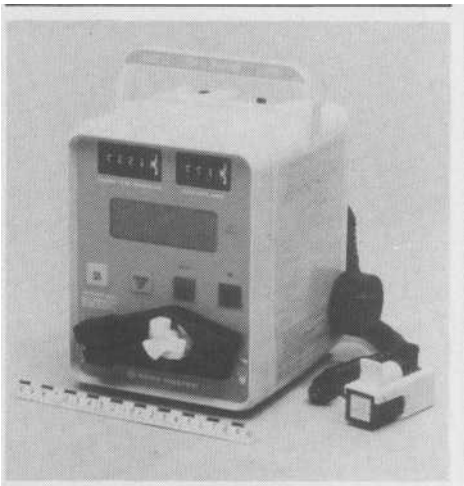

Figure 5b: The Narco AS70 pump

Figure 4a: The Braun Infusomat Secura pump

makes very little noise during operation. Consistency of the flow, at 2 ml/hr (Fig. 1g) is very regular but the device took a long time to alarm after occlusion (Fig. 2g).

Rotary Peristaltic Pumps

Critikon Simplicity 2102A (Fig. 5a)

This pump uses a rotary peristaltic mechanism. Its rotar assembly is a nylon moulding which may be detached from the pump for cleaning or renewal. It uses a dedicated infusion set with a rubber insert for loading into the rotar assembly. Flow rate is selected by push buttons over the range 1 to 999 ml/hr. There is also a facility to set the infusion time for up to 9 hours, in 1 hour steps.

As the name suggests "Simplicity" has simple controls and no nurse call alarm. It appears that this pump is designed with ease of operation in mind rather than attention to advanced features, such as air in line detector and a total volume infused counter. At infusion rates above 150 ml/hr, the pump is somewhat noisy due to the rollers rubbing against the giving set tubing. The alarm is not necessarily activated at maximum occlusion pressure (Fig. 2d). The clutch slips when fluid is not moved forward and the alarm is triggered by a drip detector when it senses "no flow".

Narco AS70 (Fig. 5b)

This uses a rotary peristaltic pumping action to administer a preset volume of fluid at a controlled rate. Its unique grooved rollers permit expansion of the pump chamber to limit the maximum pressure during occlusion. Back flow of fluid from the patient is prevented by a oneway valve situated in the lower "y" site of the infusion set. The volume infused, operating status, and device malfunction are displayed on an LCD display.

It is easy to set and operate this infusion pump; volume accuracy is excellent and its occlusion alarm is reliable. The drip sensor is extremely sensitive to splashes in the drip chamber. The alarm may be activated when filling the burrette or whilst moving the drip stand.

Reciprocating Piston Pumps

Imed 960 (Fig. 6a)

This pump has a rotary valve in the cassette directing the flow of infusion fluid to fill the cylinder as the plunger is withdrawn. This valve mechanism eliminates the possibility of a direct pathway between the bag and the patient and prevents any likelihood of uncontrolled "runaway" infusion into the patient. An alphanumeric LCD instantly

Figure 6a: The Imed 960 pump

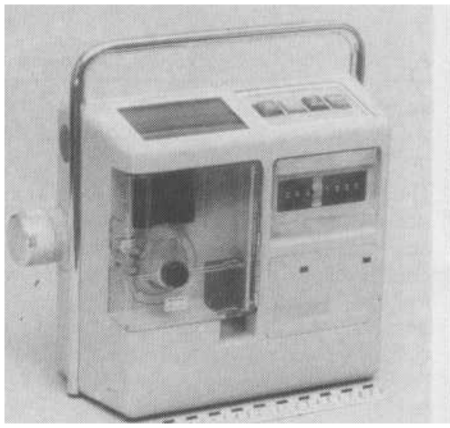

Table 2: Comparison of results for the pumps tested

Pump (Model)	Number of Observations	Mean Error (%)	Range of Error (%)	Mean Pressure Developed ± SD (mmHg)	Range of Pressure (mmHg)	Mean Time to Alarm at 1 ml/hr (min)	Mean Accumulated Fluid Expelled (ml)
Braun (Infusomat Secura)	36	2.5±1.1	0.6-4.5	626±77	480-720	39.4	0:25
Terumo (Terufusion STC502)	33	4.8±2.5	0.9-8.3	988±145	760-1180	139.3	2.82
Critikon (Simplicity 2102A	45	3.6±1.4	-6.4-5.6	816±25	780-880	89.0	0.68
Narco (AS70)	36	1.1±0.7	-1.8-2.7	742±191	340-990	18.9	0.19
Imed (960)	45	1.4±1.1	-2.8-0.5	1302±76	1150-1390	57.8	0.60
Ivac (Info-Check 1500)	45	1.3±0.6	-1.5-2.1	1256±107	1080-1360	106.5	1.23
Travenol (Flo-Gard 8000)	45	2.3±1.0	0.5-4.5	464±40	400-520	27.5	0.38
Valleylab (1V6000)	36	2.2±1.0	-0.3-4.0	802±70	710-905	41.3	0.43

shows operating status, set up procedure errors, alarm conditions and internal malfunction.

Despite many good features, such as a long-life battery pack, a large LCD panel and an excellent air-in-line alarm, the Imed 960 has limitations. It is a bulky and heavy instrument weighing 7.4 kg and the cassette can only be primed with fluid when mounted onto the pump.

Ivac Infu-Check 1500 (Fig. 6b)

This pump consists of a reciprocating piston in a disposable cassette cylinder which has inlet and outlet tubes. One of the tubes is occluded by the pump's automatic clamp mechanism depending on whether it is filling the cylinder or delivering fluid to the patient. Operating status, setting up procedures,

Figure 6b: The Ivac Infu-Check 1500 pump

internal malfunction and alarm conditions are shown promptly on an alphanumeric LED panel.

The pump is silent in operation except at the start and end of each filling cycle when the automatic clamp mechanism makes loud clicks. For low infusion rates generally used for potent drugs, for example 2 ml/hr, the time interval of no fluid delivery at filling cycle is unacceptably long (Fig. 1h). The "scrolling" alphanumeric display is difficult to read unless the instrument is mounted at the observer's eye level.

Piston Actuated Diaphragm Pumps

Travenol Flo-Gard 8000 (Fig. 7a)

This has a piston actuated diaphragm cassette designed to detect the presence of intra-chamber air by monitoring system compressibility. A drop detector monitors the drip chamber for uncontrolled free flow, empty solution container and occlusion. The flow rate is selected by digital thumbwheel switches and repeated doses may be selected in 1 ml increments over the range 1 to 999 ml by touch pad switches. A micro-processor controlled alphanumeric LED message panel guides the operator step by step through the pump's set up sequence and indicates any malfunction or error.

Figure 7a: The Travenol Flo-Gard 8000 pump

Figure 7b: The Valleylab IV 6000 pump

Priming a new cassette required meticulous care to remove air bubbles and can cause considerable wastage of fluid. It has two excellent features; the audible alarm may be adjusted to one of three sound levels and the values of the volume infused are retained in a memory if the pump is switched off. The flow pattern is regular (Fig. 1c) and the pump is moderate in size and weight.

Valleylab IV 6000 (Fig. 7b)

This uses a piston actuated diaphragm cassette with oneway inlet and outlet valves. The cassette forms an integral part of a disposable pump set which is designed to trap air, preventing it from reaching the patient. A plastic ball occludes the tubing port if the drip chamber is empty of fluid. The audible alarm provides a very distinctive and variable chime tone. Volume to be infused as well as flow rate is selected by thumbwheel switches.

The pump is fairly accurate and light in weight. Although there is no possibility of air escaping downstream to the patient, microbubbles inside the cassette can cause errors at slow infusion rates if the system is not primed meticulously. The pole clamp is poorly designed and it caused dents and cavities in the plastic coated drip stand.

Discussion

The manufacturers' promotional literature gives only the volumetric accuracy of the pumps and no information is provided on the consistency of flow. In most applications, a high degree of average flow rate accuracy is required but rapid acting vasoactive drugs demand constant flow with no short term rhythmic or abrupt fluctuations (5). It is most important that a relatively continuous flow is delivered even at low flow rates, especially for administration of drugs with a short half-life.

The results of this study demonstrated accuracy within the manufacturers' range. However, except for two pumps, the Travenol Flo-Gard 8000 and the Terumo Terufusion STC502, the flow was inconsistent and one pump, the Ivac Infu-Check 1500, delivered no fluid for more than 6 minutes at the time of the cassette filling cycle when operating at 2 ml/hr (Fig. 1h). As seen in Fig. 3, pump occlusion alarms may have a significant time delay. This depends on flow rate, the length and distensibility of the tubing, and the characteristic of the pump.

Finger peristaltic pumps can take up to 2 hours at slow rates before indicating any occlusion (6). Some devices can generate very high pressures if the catheter stop-cock is inadvertently closed (Fig. 2). Release of the occlusion may then result in the infusion of a large quantity of infusate for which certain drugs this would be highly undesirable.

Existing volumetric pumps use dedicated administration sets or cassettes and are more expensive to operate than drop counting systems using standard giving sets. In a busy Intensive Care Unit, where several brands of these devices may be in use, their operational differences often cause confusion among the nursing staff. Some cassettes are difficult to prime and waste a considerable amount of fluid.

These criticisms suggest that the ideal pump for use in intensive care has yet to be developed. There is a real clinical need for an accurate volumetric pump, with a consistent flow rate, which can be used with a standard giving set.

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Addendum

The following are names and addresses of manufacturers of equipment cited in this article.

14G Vygon Catheter
Vygon S.A., B.P.75/11 Rue Adeline, 954440 Ecouen, France

Gould-Brush 220
Gould Inc., 3631 Perkins Avenue, Cleveland, Ohio 44114, USA

S.E. Laboratories Transducer S.E.M. 4.86 and Converter S.E. 905
S. E. Laboratories (E M. L) Ltd., Spur Road, Feltham, Middlesex, UK

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