Performance of the Baxter Flo-Gard 6201 volumetric infusion pump for monoplace chamber applications

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Ray D, Weaver LK, Churchill S, Haberstock D. Performance of the Baxter Flo-Gard 6201 volumetric infusion pump for monoplace chamber applications. Undersea Hyper Med 2000; 27(2):107-112.—For non-hyperbaric purposes, the Baxter Flo-Gard 6201 volumetric pump is capable of infusing multiple types of fluids at rates of 1–1,999 ml · h⁻¹. We designed a study to determine flow accuracy of this pump at variable rates, fluid viscosities, and volumes over a range of chamber pressures. For hyperbaric use, the pump pressure sensor was adjusted. Sodium chloride solution 0.9% (NS), enteral formula, and packed red blood cells (PRBC) were infused at varying rates from 86.1 to 304 kPa (0.85 to 3.0 atm abs). For NS, measured compared to set flow rates ranged from 12.5% to 7.5% at settings of 1 and 5 ml · h⁻¹ from 86.1 to 304 kPa (0.85 to 3.0 atm abs) pressures, respectively. For NS infusions at a set rate of 100 ml · h⁻¹, the measured flow was identical to the set rate at all pressures. At flow settings of 1,999 ml · h⁻¹, the measured flow varied from the set flow by ±4.9%. Enteral infusion at 100 ml · h⁻¹ showed approximately a 3% increase in the measured vs. set flow rate. PRBC measured flow rates ranged from 0.4 to 6% of the set rate. During chamber compression and decompression, with set flow rates from 1 to 10 ml · h⁻¹, the measured flow was considerably less than expected during compression and more than expected during decompression. In conclusion, the Baxter Flo-Gard 6201 infusion pump demonstrated acceptable performance for infusing saline, enteral formula, and PRBC at low and high infusion rates into the pressurized monoplace hyperbaric chamber up to 304 kPa (3 atm abs), with the exception of low rates during compression and decompression.

*intravenous infusion, monoplace, hyperbaric oxygen therapy, technical*

Patients receiving hyperbaric oxygen (HBO₂) therapy occasionally need to have i.v. infusions during the time they are being treated. They also might require enteral tube feedings as well as packed red blood cell (PRBC) transfusions during HBO₂, particularly if they are in shock (1).

Critically ill patients may also be treated with HBO₂; for example, patients with sepsis, necrotizing fasciitis, gas gangrene, carbon monoxide poisoning, burns, smoke inhalation, crush injuries, and severe decompression illness. These patients may require carefully controlled infusions of cardiovascular vasoactive drugs, such as dobutamine, dopamine, norepinephrine, and/or epinephrine. It is important that these drugs be infused into the patient in a tightly controlled fashion, occasionally at rates as low as 1 ml · h⁻¹. We found this pump feature to be convenient, although we recognize that these medications can be diluted and infused at a more rapid rate to achieve the desired effect. Also, critically ill patients may require i.v. fluid resuscitation and blood transfusions. The Baxter Flo-Gard 6201 pump can infuse fluids up to 1,999 ml · h⁻¹. The Abbott Lifecare and IVAC 530 pumps do not have this capability (2,3).

Control of blood glucose is imperative in diabetic patients with infectious complications, such as necrotizing fasciitis. Controlled infusions of insulin might also require a pump to operate accurately as low as 1 ml · h⁻¹. Likewise, “brittle” diabetic patients might also require continuous enteral feeding, including administration of enteral nutrition during HBO₂ therapy. Providing enteral feeding during HBO₂ therapy is unusual. However, we have found the delivery of enteral feeding to be helpful in management of a diabetic patient with rhinocerebral mucormycosis who needed tight glucose control, even during HBO₂ therapy.

To our knowledge, there are three i.v. pumps that are used with monoplace chamber HBO₂ therapy. They are the IVAC 530 (IVAC Corp., San Diego, CA; IVAC no longer offers the 530, but refurbished pumps are available from the Hyperbaric Clearinghouse, Inc. Springfield, VA; and American IV Products, Inc., Hanover, MD), the Abbott Lifecare Hyperbaric Pump (Abbott Laboratories, Chicago, IL), and the Baxter Flo-Gard 6201. Performance data regarding the IVAC 530 and the Abbott hyperbaric
pump have been presented previously (2,4).

For clinical hyperbaric purposes, the IVAC 530 has several limitations. It is no longer manufactured and parts availability is limited. The IVAC 530 i.v. pump is a peristaltic pump, not a volumetric pump, so infusion accuracy may be in question. Special i.v. infusion tubing is not required. If the i.v. infusion tubing is of the adult type (20 drops \( \cdot \) ml\(^{-1} \)), the IVAC 530 cannot infuse solutions at less than 3 ml \( \cdot \) h\(^{-1} \) (infusion rate = 1 drop \( \cdot \) min\(^{-1} \)). Using infusion tubing sets with a 60 drops \( \cdot \) ml\(^{-1} \) drip chamber, the IVAC 530 can deliver 1 ml \( \cdot \) h\(^{-1} \) flow rates. Furthermore, the IVAC 530 has a maximum infusion rate of 99 drops \( \cdot \) h\(^{-1} \) which represents approximately 300 ml \( \cdot \) h\(^{-1} \). Previous testing has demonstrated that with this pump it is difficult to achieve infusion rates in excess of 200 ml \( \cdot \) h\(^{-1} \) at 304 kPa (3 atm abs) of pressure (3,5).

The Abbott Lifecare model 3HB hyperbaric pump requires a special infusion set. The Lifecare model 3HB operator’s manual does not give pump settings for infusion flow rates exceeding 800 ml \( \cdot \) h\(^{-1} \) at 304 kPa (3.0 atm abs). Although PRBC transfusions can be accomplished with both the Abbott and the IVAC pumps, the Abbott pump has difficulty infusing PRBC [one author (LKW) observed a 15–36% reduction in measured flow rate at 300 ml \( \cdot \) h\(^{-1} \) between 86.1 and 304 kPa (0.85 and 3 atm abs) (2,4)]. Additionally, the Abbott pump is not approved for PRBC infusions by the manufacturer.

Although not specifically designed for monoplace hyperbaric chamber applications, the Baxter Flo-Gard 6201 volumetric infusion pump has been used in at least one HBO\(_2\) center (5,6). Therefore, we decided to perform more extensive testing with the Baxter Flo-Gard pump to determine its application and suitability for use with monoplace chamber HBO\(_2\) applications.

**METHODS**

A new Baxter Flo-Gard 6201 infusion pump was loaned to us for testing purposes by Baxter Healthcare Corporation. Continu-Flo solution sets were also provided (cat #2C5527s, Baxter Healthcare Corp., Deerfield, IL). The Baxter pump operation was reviewed and the pump was set up according to Baxter’s specifications. The hyperbaric pass-through (cat. #041-600-500A, Argon Corp., Division of Maxxim Medical, Athetic, TX) was placed through the hatch of a Sechrist 2500 B monoplace hyperbaric chamber (Sechrist Incorporated, Anaheim, CA) in the standard fashion. Fluid was collected within the confines of the hyperbaric chamber.

We initially attempted 0.9% normal saline solution with this Baxter pump set at 200 ml \( \cdot \) h\(^{-1} \). As the chamber pressure exceeded approximately 202.6 kPa (2.0 atm abs), the pump activated a pressure alarm and ceased to infuse the saline. Correspondence with the Baxter Flo-Gard engineers indicated that the sensitivity of the pressure sensor could be adjusted, which would probably permit the pump to operate up to 304 kPa (3 atm abs).

Following procedures that are outlined in the Baxter Flo-Gard 6201 service manual, the biomedical engineering department at our hospital made changes to the pressure sensor sensitivity. By removing the cover to the downstream occlusion sensor and turning the sensor approximately 2½ turns counterclockwise from the standard settings, an alarm limit of 3 atm abs was achieved. Pressure was tested by attaching a pressure gauge to the end of an i.v. set installed in the pump. Note that once the desired pressure limit was measured on the gauge, the gauge was disconnected from the i.v. set to release pressure, and the entire process was repeated 2–3 times to ensure accuracy. Instructions for downstream occlusion sensor calibration can be found in the Baxter Flo-Gard 6201 manual in section 6.4.3.

Bench testing indicated that the pressure alarm would stop pump function at approximately 304 kPa (3 atm abs). With saline infusing at 200 ml \( \cdot \) h\(^{-1} \), the pump seemed to operate satisfactorily up to 304 kPa (3 atm abs) pressure. Occasionally the pressure alarm would signal, but the pump could easily be restarted by pressing the primary start (PRI START) button. We proceeded to test the Baxter pump over a range of infusion rates, solution types, and chamber pressures.

For infusions, we used sodium chloride solution 0.9% (NS), undiluted enteral feeding (Subdue, Mead Johnson Nutritionals, Evansville, IN 47721), and PRBC. Rates of infusion for NS were 1, 5, 100, and 1,999 ml \( \cdot \) h\(^{-1} \). For the 1 and 5 ml \( \cdot \) h\(^{-1} \) rates, the pump was run continuously for 4 h, to increase the signal-to-noise ratio in the measurements. Tests at speeds of 100 and 1,999 ml \( \cdot \) h\(^{-1} \) were run in 0.5-h increments. The enteral formula was infused at 100 ml \( \cdot \) h\(^{-1} \) for 0.5 h. Packed red blood cells were infused at 100 ml \( \cdot \) h\(^{-1} \) and at 1,999 ml \( \cdot \) h\(^{-1} \) for 0.5 h. The chamber pressure for testing purposes ranged from 86.1 kPa (0.85 atm abs, which is our altitude of 1,500 m above sea level), 202.6, 253.2, and 304 kPa (2.0, 2.5 and 3.0 atm abs, respectively). Graduated cylinders and graduated burettes were used to quantify volumetric measurements accurately.

Because it is possible that rapid infusions of PRBC with this pump might cause hemolysis, we inspected pre- and posttransfusion PRBC samples for evidence of hemolysis.
by performing free-serum hemoglobin measurements.

It is possible that during chamber compression or decompression or both, the set infusion rate might be affected. We established two separate sets of experiments where low infusion rates of NS were used (1, 5, and 10 ml \( \cdot \) h\(^{-1} \)) with the chamber compressed from atmospheric pressure to 3043 kPa (3 atm abs). We tested NS infusions at these low rates with a 10-min compression and 10-min decompression, as well as with a 20-min compression and a 20-min decompression. The volume of the saline was measured with a calibrated burette for each 10- and 20-min interval.

Since the Baxter pump is a peristaltic, volumetric infusion pump, we were also interested in how many times the same infusion tubing could be used and maintain similar flow rates (i.e., how often would the tubing set need to be changed?). Pump trials were run using Continu-Flo infusion sets for 2 or more days, then repeated using the infusion set for one day only.

Data will be expressed as measured minus (−) the set rate divided (+) by the set rate multiplied (×) by the percent (%). All testing was performed with two new Baxter Flo-Gard pumps to determine pump reproducibility.

RESULTS

Before pressure sensor adjustment, the pumps were unable to function at chamber pressures that were greater than 222.9 kPa (2.2 atm abs). After pressure sensor adjustment, the Baxter Flo-Gard 6201 pumps were able to infuse solutions into a chamber compressed up to 304 kPa (3 atm abs).

For saline, at 1 and 5 ml \( \cdot \) h\(^{-1} \) at 86.1 kPa (0.85 atm abs) there was an increase in flow. A slight reduction occurred in the amount of saline infused at 202.6–304 kPa (2–3 atm abs). At 5 ml \( \cdot \) h\(^{-1} \), the pump performance demonstrated an overall increase of measured compared to expected volume. At 100 ml \( \cdot \) h\(^{-1} \), there was no significant difference between set flow rates and actual flow rates. At flow rates of 1,999 ml \( \cdot \) h\(^{-1} \), the Baxter pump performed satisfactorily, including at 304 kPa (3.0 atm abs) (Fig. 1).

The enteral formula infusion rate increased 3.6% at 0.85; 3.8% at 2.0; 3% at 253.3 kPa (2.5 atm abs); and 1.4% at 304 kPa (3.0 atm abs) over expected rates, respectively. For PRBC cell infusions (100 and 1,999 ml \( \cdot \) h\(^{-1} \)), the measured infusion volumes were similar to those shown for saline infusions (Fig. 2).

There was no evidence of increased hemolysis with transfusion of PRBC (Fig. 3).

For low rate infusions (1–10 ml \( \cdot \) h\(^{-1} \)) during chamber compression and decompression, we found considerable differences between the measured and the expected infused volumes (Table 1, Fig. 4). The fluid volume measured immediately after a 10-min and a 20-min compression to 304 kPa (3.0 atm abs) at 1 ml \( \cdot \) h\(^{-1} \) indicated that fluid moved retrograde instead of forward. In all instances, measured volumes during compression were lower than expected. Volumes measured during decompression were significantly higher than expected. However, if the measured volumes during compression and decompression were added, the sum of the measured volumes was similar to those expected. Table 1 and Fig. 4 are representative of the 10-min interval trials. Results for 20-min interval trials are similar to results for 10-min interval trials and are not shown graphically.

We also observed that measured volumes compared to expected fluid volumes decreased with extended use of the
Continu-Flo tubing. We compared two trials of pump performance with tubing used for two consecutive days to that of previously unused tubing. In two separate tests, using NS infused over 30 min at a rate of 100 ml·h⁻¹ at 86.1 kPa (0.85 atm abs), we found that the 2-day-old tubing had a measured vs. ideal change of -8 and -7.6%, respectively. The new tubing had a measured versus ideal change of 7% and 8%, respectively.

Limited saline trials were performed on two Baxter Flo-Gard 6201 infusion pumps to determine reproducibility of delivered volumes. At pressures ranging from 86.1 to 304 kPa (0.85 to 3.0 atm abs), and pump speeds of 1, 5, and 100 ml·h⁻¹, the majority of compared measured volumes delivered by both pumps was ±5%.

DISCUSSION
The performance of the Baxter Flo-Gard 6201 infusion pump is satisfactory for use with monoplace hyperbaric medicine applications. For chamber pressures up to approximately 2 atm abs, no pressure sensor adjustment is necessary. However, we did not conduct performance trials with this pump before pressure sensor adjustment. After pressure sensor adjustment, the pump operated satisfactorily up to 3 atm abs chamber pressure.

Our data indicate that this pump is suitable for use with controlled infusions of crystalloid solutions at rates as low as 1 ml·h⁻¹. The ability of this pump to deliver very low volumetric infusions is attractive when patients with vasactive drugs or insulin infusions require HBO₂ therapy.

Infusions up to 1,999 ml·h⁻¹ can only be performed with the Baxter Flo-Gard infusion pump. Therefore, if a patient is in shock or is hemodynamically unstable (e.g., severe burns or debrided necrotizing soft tissue infections with large i.v. fluid requirements), the Baxter infusion pump might be particularly helpful. Examples and discussion regarding limitations of i.v. therapy in patients in shock treated within the monoplace hyperbaric chamber suggest that the capability of the Baxter Flo-Gard pump could be valuable (1,4). With large volume infusion rates, accuracy is not critically important, although the pump performed equally well during hyperbaric conditions as it did when operated at atmospheric pressure.

For patients requiring continuous infusions of insulin, or those who have brittle diabetes, continuing enteral feeding during their HBO₂ therapy may be indicated. The Continu-Flo set can be converted for enteral feedings by attaching an Abbott screw cap adapter (Abbott Laboratories, North Chicago, IL) to the i.v. spike. The screw-cap adapter will fit most standard 1-liter saline bottles, which

<table>
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<th>Flow rate, ml·h⁻¹</th>
<th>Compression, 10 min</th>
<th>Decompression, 10 min</th>
<th>Compression/Decompression, 120 min</th>
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can be emptied and filled with formula. Caution is imperative to prevent enteral feeding solution from being inadvertently infused i.v. by mistake (7,8).

The compliance (e.g., change in tubing volume with a change in i.v. tubing pressure) of the Baxter Contiu-Flo infusion set proved to be a disadvantage in our testing. It was more likely to occlude during compression than the IVAC pump tubing and may have been a factor in fluctuating compression/decompression volumes that we observed. Even though the Contiu-Flo sets may be used continuously for up to 72 h as per Centers for Disease Control guidelines (9), we observed that the infused volume decreased significantly with use greater than 24 h (typically more than three compression cycles during this trial). Therefore, after 24 h of use, we expect that true flow will be lower than the set flow rate.

We are aware of two other pumps tested recently: the Baxter Patient-Controlled Analgesia (PCA) infusion (8) and the Atom 235 syringe infusion pump (9,10). All three studies reported favorable results for use in a hyperbaric setting. However, because of differences in pump design and testing methods, it is difficult to directly compare results to our pump data.

The Baxter PCA infuser is operated by an elastomeric balloon reservoir, controlled by a flow restrictor. This study addressed variations in ambient temperature and viscosity of delivered fluids. It did not address whether the changing elasticity of the balloon reservoir during emptying affected fluid delivery, nor was there any data on compression/decompression variances of measured fluid volume (8).

The Atom 235 syringe infusion pump data may have some correlation to the compression data that we observed (9,10). Both the Atom 235 and Baxter 6201 studies revealed a lower-than-expected delivered volume during compression. Data in each study indicate that accurate delivery of low volume medications may be affected during the compression phase of a hyperbaric treatment and may warrant careful monitoring of the patient for dose-related symptoms.

We found the Baxter Flo-Gard 6201 pump to be easy to operate. It has a single, front-loading channel and does not use a drop sensor. Although we tested only primary infusion capabilities, the pump also performs secondary infusions and can be programmed concurrently with the primary infusion. The secondary rate is selectable from 1 to 999 ml · h⁻¹ in 1 ml · h⁻¹ increments. After the infusion is complete, the pump automatically switches to 5 ml · h⁻¹, keep vein open (KVO) rate, or a lesser rate, if programmed.

Periodic maintenance requirements are minimal. The pump mechanism and case can be cleaned with soapy water or Hi-Tor Plus (Huntington Labs, Huntington, IN), among other cleaning agents listed in the pump manual. The pump operates on standard electrical power, or on its self-contained rechargeable battery. Battery life is approximately 6 h. Annual inspection and testing should be performed yearly by the hospital’s biomedical engineering department.

In conclusion, we feel the Baxter Flo-Gard 6201 will be potentially valuable in monoplace hyperbaric medicine departments that treat patients who need intravenous infusions or enteral infusions. This pump is particularly helpful for controlled infusions at very slow rates (e.g., insulin or vasoactive drugs or both) and for the delivery of large volumes of crystalloid or PRBC, as well as controlled infusions of enteral feeding. It must be noted, however, that tubing compliance may affect fluid volumes delivered by the pump, especially when set rates and volumes are minimal. Careful monitoring of patients with low volume infusions during the compression and decompression phases of HBO₂ is advised.

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REFERENCES
