

Technical Communication

# Comparison of three intravenous infusion pumps for monoplace hyperbaric chambers.

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Weaver LK, Ray, D., Haberstock D. Comparison of three intravenous infusion pumps for monoplace hyperbaric chambers. *Undersea Hyperb Med*; 32(6):451-456. We compared the infusion accuracy of the Baxter Flo-Gard® 6201, IVAC® 530 and Abbott Lifecare®3HB pumps with saline and enteral formula at chamber pressures from 86.1 kPa (0.85 atm abs) to 304 kPa (3.0 atm abs). The Baxter pump infused  $\pm 10\%$  saline at all tested pressures and rates (1-1,999 ml/hr). At 1 ml/hour, the IVAC infused 18% more saline than expected (86.1 kPa). The Abbott infused -15% and -23% than expected at 202.6 kPa (999 ml/hr) and 304 kPa (800 ml/hr), respectively. A 10-minute chamber compression and decompression (86.1-304-86.1 kPa) resulted in lower-than-expected measured volumes during compression (64-112%) and higher-than-expected measured volumes during decompression (62-114%) at rates of 1, 5, and 10 ml/hr for all pumps. Enteral infusions (100 ml/hour) resulted in -20% to +12% fluid volume discrepancies. In conclusion, the Baxter pump had the best overall performance. Changes observed during compression and decompression may be clinically important.

## INTRODUCTION

Many patients treated with hyperbaric oxygen (HBO<sub>2</sub>) in monoplace hyperbaric chambers require continuous intravenous (IV) infusions during treatment. Intravenous infusions include crystalloid solutions and medications such as antibiotics, anxiolytics, analgesics, and others. Patients with life-threatening illnesses such as severe sepsis, gas gangrene, and necrotizing fasciitis may need large volume IV infusions and carefully controlled infusions of cardiovascular vasoactive drugs or insulin delivered at rates as low as 1 ml/hr. Rapid fluid resuscitation may be necessary while treating some critically ill

patients during HBO<sub>2</sub> therapy (1, 2). Critically ill patients also warrant aggressive, tight glucose control with insulin infusions to reduce mortality (3). Therefore, accurate insulin infusions are potentially important during HBO<sub>2</sub> therapy.

Although enteral feeding may be discontinued for HBO<sub>2</sub> therapy, there are some circumstances where continuing enteral feeding during HBO<sub>2</sub> therapy might be important. For example, a patient with brittle diabetes needing a continuous insulin infusion during twice daily HBO<sub>2</sub> treatments for severe infection might have glucose instability if enteral feeding is

discontinued.

Previously, we tested the Baxter Flo-Gard® 6201 infusion pump (Baxter Healthcare Corporation, Deerfield, Illinois 60015) (4). Although the Baxter pump performed well for monoplace hyperbaric chamber application, it was not originally intended for this purpose. Two other pumps are used with monoplace hyperbaric chambers in the United States. These are the IVAC 530® (IVAC Corp., San

Model 530 and Abbott Lifecare® Model 3HB infusion pump performance was compared. All data reported from the Baxter Flo-Gard® 6201 infusion pump were derived from our previous trial (4). Continu-Flo® solution sets (Cat #2C5527s, Baxter Healthcare Corp., Deerfield, IL 60015) were used with the Baxter® infusion pump. IVAC Spec-Sets® infusion sets (Cat #652181, IVAC Corporation, San Diego, CA 92121-1579) were used with the IVAC infusion

**Table 1: Infusion pump comparison**

Pump	Type	Flow Rate (ml/hr)		Enteral	Safety Lock	Flow Sensor	Primary/Secondary Infusions
		Minimum	Maximum				
Baxter®	Volumetric	1	1,999 <sup>a</sup>	Y	Y	Internal	Y
IVAC®	Peristaltic	3 <sup>b</sup>	297 <sup>b</sup>	Y	N	External	N
Abbott®	Volumetric	10	999 <sup>c</sup>	Y	Y	External	N

<sup>a</sup> For primary infusions only. The maximum rate for secondary infusion is 999 ml/hr

<sup>b</sup> With adult (20 drops/ml) infusion set. If using a pediatric drip chamber (1 drop/ml), the minimum rate = 1 ml/hr and the maximum rate = 99 ml/hr.

<sup>c</sup> Up to 202.6 kPa only. At 304 kPa, the maximum infusion rate is 800 ml/hr

Diego, California; IVAC no longer offers the 530, but refurbished pumps are available from the Hyperbaric Clearinghouse, Inc., Springfield, Virginia, and American IV Products, Inc., Hanover, Maryland 21076), and the Abbott Lifecare® 3HB Hyperbaric Pump (Abbott Laboratories, Chicago, IL 60064). Limited data regarding the IVAC 530® (5, 6) and the Abbott Lifecare® 3HB (5) performance has been presented previously. Table 1 compares features of these three pumps.

This study compared the performance of these three monoplace-capable IV infusion pumps. In previous testing, the Baxter Flo-Gard® 6201 pump proved to be satisfactory for measured volume accuracy under all experimental conditions except monoplace chamber compression and decompression (4).

## METHODS

The Baxter Flo-Gard® 6201, IVAC®

pump. Specialty IV Pump Sets-HB (Cat #11155, Abbott Laboratories, North Chicago, IL 60064) were used with the Abbott® infusion pump. A hyperbaric pass-through (Cat #041-600-500A, Argon Corp., Division of Maxxim Medical, Athens, TX 75751) was placed through the hatch of a Sechrist 2500 B monoplace hyperbaric chamber (Sechrist Incorporated, Anaheim, CA) in the standard fashion. Fluid was collected by calibrated burettes within the confines of the monoplace hyperbaric chamber.

Normal saline (0.9% NaCl) or undiluted enteral feeding (Subdue®, Mead Johnson Nutritionals, Evansville, IN 47721) was used for infusions. Saline infusion rates were 1 ml/hr, 5 ml/hr, 100 ml/hr, and at each pump's maximum flow setting (1,999 ml/hr for the Baxter Flo-Gard® 6201 pump, 297 ml/hr for the IVAC® 530 pump, and 800 to 999 ml/hr, depending on chamber pressure, for the Abbott Lifecare® 3HB pump) (Table 1). Maximum infusion rate tests were performed

over 10-minute intervals. Tests at pump set rates of 100 ml/hr were performed over 30-minute intervals. For the 1-ml/hr and 5-ml/hr rates, the pumps operated continuously for 4 hours at each chamber pressure to increase the signal-to-noise ratio in the measurements. Enteral formula was infused at 100 ml/hr for 30 minutes.

To measure pump accuracy during chamber compression and decompression, we infused normal saline over a 10-minute compression to 304 kPa (3.0 atm abs) and subsequent decompression of the chamber over 10 minutes from 304 kPa to normobaric pressure (86.1 kPa, 0.85 atm abs) at 1, 5, and 10 ml/hr.

Data are expressed as measured minus (-) the set rate divided (÷) by the set rate multiplied (x) by the percent (%).

## RESULTS

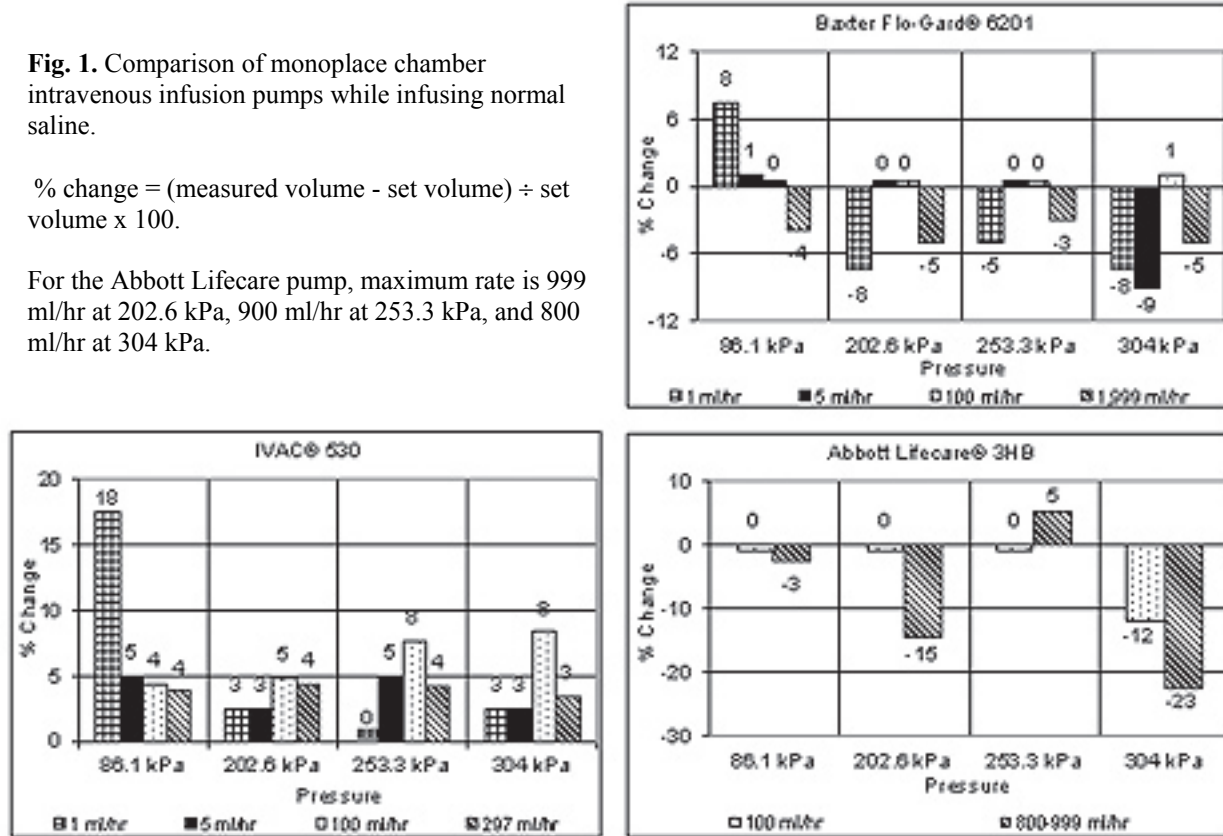
**Fig. 1.** Comparison of monoplace chamber intravenous infusion pumps while infusing normal saline.

$$\% \text{ change} = (\text{measured volume} - \text{set volume}) \div \text{set volume} \times 100.$$

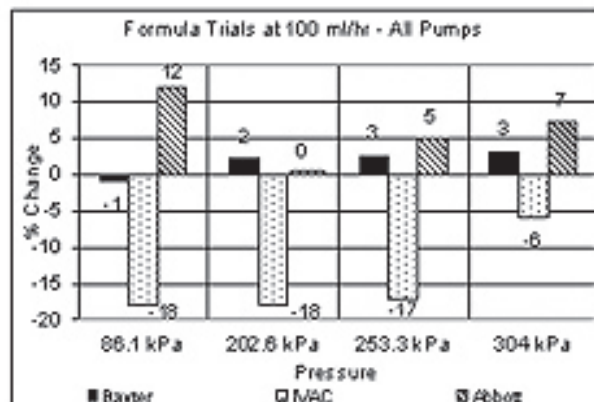
For the Abbott Lifecare pump, maximum rate is 999 ml/hr at 202.6 kPa, 900 ml/hr at 253.3 kPa, and 800 ml/hr at 304 kPa.

Saline trials at pump rates of 1 ml/hr and 5 ml/hr for the Baxter Flo-Gard® 6201 and IVAC® 530 pumps resulted in an accuracy range of ±10% of the set volume, with the exception of an 18% measured volume increase at 1 ml/hr with the IVAC® pump at ambient pressure (86.1 kPa). At 100 ml/hr, the measured saline volumes were within the ±10% range with the exception of the Abbott Lifecare® 3HB pump, which showed a 15% reduction in measured versus set volumes at 304 kPa (Figure 1).

For the maximum set infusion rates, the measured volume vs. set volume accuracy ranged from 23% less-than-expected to 4% greater-than-expected, depending on the chamber pressure, and the pump (Figure 1). For enteral formula trials, the measured vs. set values were most accurate with the Baxter® pump (measured vs. set volumes were -1% to +3% from 86.1 kPa to 304 kPa, respectively) and least accurate with the IVAC® pump



(measured vs. set volumes were -6% to -18%) (Figure 2).



**Fig. 2.** Comparison of monoplace hyperbaric chamber infusion pumps while infusing enteral formula.

$$\% \text{ change} = (\text{measured volume} - \text{set volume}) \div \text{set volume} \times 100.$$

**Fig. 3.** Comparison of monoplace chamber intravenous infusion pumps while infusing normal saline during compression and decompression.

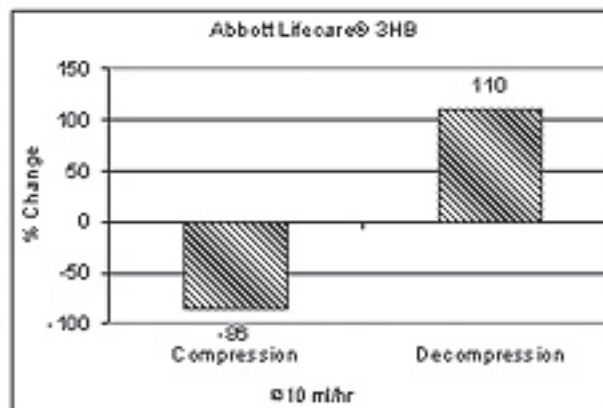
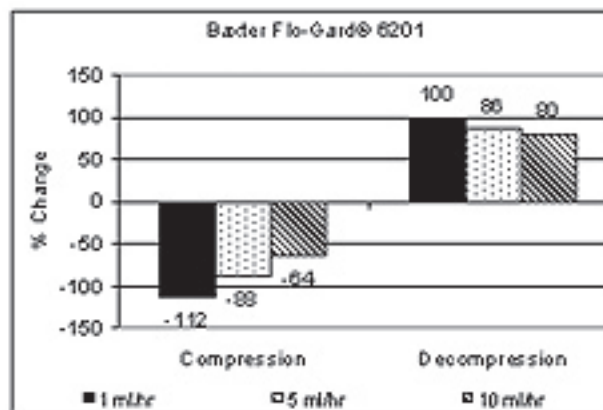
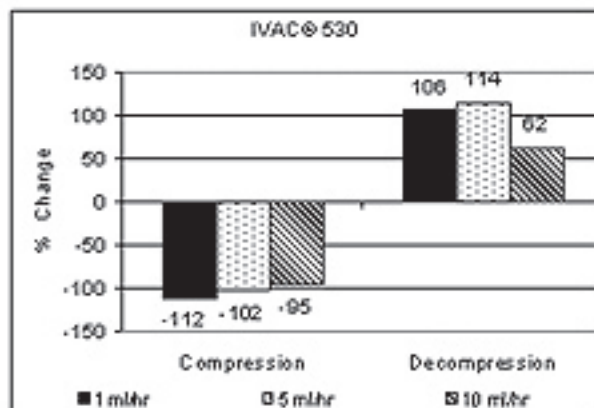
$$\% \text{ change} = (\text{measured volume} - \text{expected volume}) \div \text{expected volume} \times 100.$$

The expected infused volumes were 0.17, 0.83, and 1.67 ml at 1, 5, and 10 ml/hr, respectively, for 10 minutes. The Abbott pump was tested only at 10 ml/hr because it cannot be operated on lower infusion rates (Table1).

The measured infused volumes (1, 5, and 10 ml/hr x 10 minutes) were less than expected during a 10-minute compression to 304 kPa. The measured volumes were more than expected during a 10-minute decompression from 304 kPa for all three pumps at all three set rates (Figure 3).

## DISCUSSION

The Baxter, IVAC, and Abbott pumps are all used to deliver fluids and medications intravenously to patients compressed in monoplace hyperbaric chambers. Comparison of data gathered for all pump trials indicates that the Baxter Flo-gard® 6201 infusion pump had the best overall measured fluid volume accuracy for infusions performed at varying speeds and pressures. For saline infusions,



the Baxter Flo-Gard® 6201 pump performed better than the other pumps at all tested rates and chamber pressures. The IVAC® 530 infusion pump was the second-most accurate, and the Abbott Lifecare® 3HB pump was the least accurate. The Baxter Flo-Gard® 6201 was also the most accurate pump for enteral feeding solutions at 100 ml/hr up to 304 kPa. The IVAC® 530 and Abbott Lifecare® 3HB had large delivered fluid volume variances (set volume vs. measured volume) with enteral formula infusions.

We found large reductions in infused fluid at lower infusion rates (1 to 10 ml/hr) with all pumps during chamber compression. During chamber decompression, more fluid than expected was infused. These observations are clinically important. In patients with septic shock, we often observe an increased need for pressors to maintain an adequate blood pressure during patient compression and a decreased pressor requirement during patient decompression. Undoubtedly, this blood pressure variability is due to IV tubing distensibility and capacitance, with varying infusions of pressors during chamber compression and decompression. Shortening the length of IV tubing between the IV pump and the chamber pass-through might reduce this variability. Another option includes manufacturing less distensible, low-capacitance IV tubing for monoplace hyperbaric chamber applications.

Although comparison of pump accuracy has been discussed previously (4), it is important to note that there are measured vs. set fluid volume variances in all pumps when tested for delivery of different types of fluids. Greater fluid viscosity appears to adversely affect delivered volume accuracy, particularly with use of the IVAC® 530 and Abbott Lifecare® 3HB pumps.

Pump versatility is important in centers that routinely perform intravenous infusions

during HBO<sub>2</sub> treatments. In some centers it is common to infuse one or more medications during HBO<sub>2</sub> therapy. For example, in patients receiving multiple antibiotics for wound infections, we find it helpful to have an in-chamber primary and secondary antibiotic infusion to keep the patient on his/her medication schedule. The Baxter Flo-Gard® 6201 infusion pump can be programmed for primary and secondary infusions at the same time. Unlike the IVAC® 530 and Abbott Lifecare® 3HB pumps, the Baxter Flo-Gard® 6201 programmed fluid volume and delivery rates always reflect the actual flow rates and fluid volumes being delivered. It can also be programmed for primary and secondary infusions at differing fluid volumes and speeds. Accumulated volumes from primary and secondary infusions can be displayed on demand. The IVAC® 530 and Abbott Lifecare® 3HB cannot perform primary and secondary infusions in this manner.

Limitations of our study include: (1) We do not know if all pumps of a particular manufacturer have similar performances; and (2) We do not know the intra-pump variability. We did not test an individual pump repeatedly, so we cannot comment upon intra-pump variability. Since we did one trial for each pump, at each flow rate and pressure, a statistical analysis is not possible.

Operator manuals for both the Abbott® (7) and Baxter® (8) pumps state that periodic cleaning of the pump can be accomplished with a mild solution of soapy water. Alcohol or soapy water may be used to clean the flow detector of the Abbott® pump. The Baxter® operator's manual lists several other solutions suitable for pump cleaning. An operator's manual is no longer available for the IVAC® 530 pump, but company representatives suggest cleaning the pump with a mild soap and water solution, also. Periodic maintenance requirements on all three pumps are to be performed by each facility's

biomedical engineering department according to facility guidelines.

The Baxter Flo-Gard® 6201 infusion pump was released for sale in February 1992. It has had minor upgrades related to pump service since that time, which have not impacted operator use. At the present time, technical assistance and replacement parts are available. However, we have been disappointed regarding technical questions about adjusting the pressure sensor, suggesting Baxter is not interested in supporting the 6201 pump for monoplace chamber applications. The IVAC® 530 may be difficult to maintain because of limited access to parts and service availability. The IVAC® 530 infusion pump was manufactured from January 1979 to June 1987. In 1997, the manufacturer terminated parts and technical assistance for this pump. The Abbott Lifecare® 3HB pump was first marketed in July 1990. Minor upgrades have been made to the pump since that time. These upgrades have not impacted operator use. The Abbott Lifecare® 3HB pump is no longer manufactured.

In summary, the Baxter Flo-Gard® 6201 volumetric infusion pump was the most accurate and versatile of the pumps tested in this trial. However, this pump was not originally intended, nor recommended, for use in patients in monoplace hyperbaric chambers. Adjustment and subsequent testing of pressure sensitivity must be performed by a qualified person using guidelines in the pump service manual. When purchasing or operating any infusion pump in hyperbaric chambers, suitability for specific needs and availability of parts and technical support are important considerations.

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