

Management of Gravity Intravenous Infusions in an Austere Environment Using the DripAssist Infusion Rate Monitor

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The US Army's 541st Forward Surgical Team (FST) deployed in support of Operation Inherent Resolve–Syria in 2017. Throughout the deployment the 541st FST provided surgical and anesthesia services to US, coalition, and partner forces in numerous austere environments. Following an enemy attack, the FST received multiple casualties and provided a total of 7 critical medication infusions to 3 patients without the aid of electronic-controlled intravenous (IV) infusion pumps or syringes for 10 hours while the wounded soldiers waited for evacuation to a higher level of care. The team administered propofol, norepinephrine,

tranexamic acid, and ketamine by individual gravity infusions relying solely on counting drops. An infusion rate monitor (DripAssist, Shift Labs Inc) was used to assist in initial IV rate setup and maintenance. The medics and nurses of the 541st FST found that the infusion rate monitor improved the speed of setting the IV infusion rate, drop counting accuracy, and the team's ability to monitor the continuous delivery of gravity IV infusions.

Keywords: DripAssist, gravity, intravenous infusion, total intravenous anesthesia (TIVA).

Providing medical care in austere environments offers unique challenges. Austere conditions can be found in areas of armed conflict, those served by wilderness medicine, medical missions in developing countries, and even here in the United States and its territories stricken by natural disasters. In 2017, Hurricanes Maria, Irma, and Harvey created vast areas of destruction and severely affected public utility infrastructures.¹ Three months after Hurricane Maria made landfall in Puerto Rico, 45% of the island remained without electricity.² US Army Regulation 40-501 defines an austere environment as follows:³

1. An area that regularly experiences significant environmental hazards (for example, heat, cold, altitude, aerosol particles) that would exacerbate existing medical conditions when protection (such as climate control) is not available

2. An area that has limited access to a reliable source of electricity

3. An area where force protection levels mandate prolonged use of body armor and or chemical protection equipment.

In noncombat areas, medical providers face similar austere environmental challenges: terrain, weather, reliable electricity, consistent resource resupply, and hardened structures in which to work.^{4,5} These harsh environmental conditions impact the medical team's efforts to provide care to the sick and injured. By its very nature, an austere environment presents the opportunity to care for trauma victims without the support and technology that exist in many hospitals today. Fluid resuscitation

and intravenous (IV) medication therapy are integral parts of Advanced Trauma Life Support (ATLS),⁶ and many trauma victims often require resuscitative surgery, the administration of anesthesia, and intensive care. Total intravenous anesthesia (TIVA) is arguably the most compact, portable, robust, and complete anesthetic delivery system for the austere environment.^{7,8} A key component of TIVA is the precise control offered by electronic-controlled IV infusion pumps. Electronic infusion pumps rely on consistent voltage-regulated electrical power, and most include rechargeable battery backup. The fundamental lack of electricity in most austere environments is a critical issue. In austere environments it is common to use nonelectronic in-line IV rate controllers such as flow regulators (eg, Dial-A-Flo, Hospira, now ICU Medical Inc). However, flow regulators must be used according to the manufacturer's specifications to offer consistent, safe delivery.

Presented here is a case study involving 3 critically wounded patients who required multiple infusions of IV medications in the austere environment of an armed conflict zone. Unfortunately, our electronic IV infusion pumps arrived in the operating theater inoperable. The team relied on flow regulators and counting drops for setting and maintaining the IV rate with the assistance of a new medical device, the DripAssist infusion rate monitor (Shift Labs Inc). For those healthcare providers who routinely work in modern hospitals or surgery centers, administering medication by gravity and counting drops might be considered old-school nursing care because electronic IV infusion pumps are readily avail-

able. Nonetheless, gravity infusion and counting drops is a skill set that continues to be used in certain situations and can prove lifesaving while rendering medical care in austere conditions (Figure).

Case Summaries

The 541st Forward Surgical Team (FST) (Airborne) deployed in support of Operation Inherent Resolve–Syria in 2017. Because of the highly mobile nature of our mission and the requirement to maintain a small mobile footprint, we were required to be selective when packing medical equipment and supplies. Using TIVA as the sole means of delivering anesthesia downrange eliminated the need for drawover vaporizers and inhalation anesthetics. Unfortunately, our multichannel IV infusion pumps arrived nonoperational and remained unrepairable for the duration of the deployment. Therefore, the team used gravity infusions and counting drops to quantitate IV infusion rates as well as medication administration including TIVA. Only a limited number of flow regulators and 60-drop tubing were immediately available for our use. Medication infusions were administered by gravity using standard-drop tubing (10, 15, 20, and 60 drops/mL) with a roller clamp for rate adjustment. The team contacted Shift Labs to procure an infusion rate monitor (DripAssist) to improve the accuracy and monitoring of gravity infusions.

After an attack on our coalition firebase, the FST received multiple casualties.

- **Case 1.** Patient 1 was a 25-year-old man weighing approximately 75 kg. He ambulated into the FST tent complaining of right-sided head pain. The ATLS primary survey revealed penetrating wounds above the right eye, at the base of the right skull, and on the right shoulder anteriorly and posteriorly, as well as bilateral midhigh anterior wounds with corresponding posterior wounds. On admission, his vital signs were as follows: blood pressure (BP) of 138/90 mm Hg, pulse of 95/min, respiratory rate (RR) of 18/min, arterial oxygen saturation (SaO₂) of 94% on room air, and temperature of 37.4°C (99.3°F). His Glasgow Coma Scale score was 15. Fifteen minutes later the patient had a seizure with full decorticate posturing lasting approximately 1 minute. Three milligrams of midazolam was administered intravenously, followed by an additional 2 mg IV. We initiated traumatic brain injury (TBI) protocol,⁹ including a 250-mL IV bolus of 3% normal saline solution (NSS) and 500 mg of levetiracetam IV. Within 5 minutes the patient was moving all extremities and appeared to be in a postictal state. We secured the airway and continued with the TBI protocol to include 3% NSS at 50 mL/h. Following a rapid sequence induction with propofol and rocuronium, a propofol infusion was started to maintain sedation.

- **Case 2.** Patient 4 was a 20-year-old woman weighing approximately 70 kg. She sustained a single gunshot



Figure. DripAssist Infusion Rate Monitor (Shift Labs)

wound to the left foot. Vital signs were as follows: BP of 146/79 mm Hg, pulse of 96/min, RR of 30/min, and SaO₂ of 97% on room air. While in the delayed triage area, she received an 800- μ g fentanyl lozenge, 150 μ g of IV fentanyl, 9 mg of IV morphine, 3 mg of IV midazolam, 4 mg of IV ondansetron, 1 g of IV acetaminophen, and 50 mg of IV ketamine. After her transfer to an ATLS litter, the orthopedic surgeon administered a left ankle block with a total of 30 mL of 0.5% bupivacaine. Approximately 3 hours later the patient rated her pain as 8 on a 10-point scale. Therefore, we started a ketamine infusion at 0.2 mg/kg/h. From our previous experience with gravity infusions, we recognized that making a dilute solution of ketamine would provide us the opportunity to run the rate slightly faster, decreasing the chance of error associated with very slow infusions. Diluting the solution and using a background carrier fluid provided a steady-state administration, which resulted in an improvement in the patient's pain score and decreased vocalization.

- **Case 3.** Patient 6 was a 30-year-old man weighing approximately 70 kg who arrived unresponsive with penetrating trauma to the right neck at the border of neck zone 2 and zone 3¹⁰ with bleeding from the right ear. There were nonpenetrating wounds to the right side of the abdomen and the right upper thigh. Vital signs were: BP 114/64, pulse 99, RR 16, SaO₂ 97% on room air, and temperature of 35.3°C (95.5°F). As part of our TBI protocol, we administered a 250-mL IV bolus of 3% NSS as well as 500 mg of IV levetiracetam, 1 g of IV cefazolin, 1 g of IV tranexamic acid, and intramuscular tetanus vaccine. Following rapid sequence induction with propofol and rocuronium, we secured the airway and continued the TBI protocol by administering 3% NSS at 50 mL/h along with a propofol infusion for sedation and 1 g tranexamic acid infused over 8 hours. Over the course of the next several hours, the patient's blood pressure and heart rate were labile with bouts of bradycardia and hypertension followed by hypotension. A norepinephrine infusion was started to maintain mean arterial pressure at 90 mm Hg.

Due to continued enemy activity in the area, all patients remained in the FST for 10 hours. In summary, 3 trauma

patients who needed the most care required maintenance of 7 critical infusions while awaiting transportation to a higher level of care. We maintained propofol infusions for patients 1 and 6 at 20 to 200 $\mu\text{g}/\text{kg}/\text{min}$. Patient 6 received a maintenance norepinephrine infusion at 0.05 to 0.3 $\mu\text{g}/\text{kg}/\text{min}$ and tranexamic acid (1 g in 250) infused over 8 hours. Patient 4 received a ketamine maintenance infusion at 0.2 mg/kg/h. Each of the infusion rates was set using the DripAssist infusion rate monitor. Over the course of 10 hours, we rotated the infusion rate monitor among each of the 7 infusions to confirm accuracy and adjustment of the infusion rates as needed.

Discussion

Administering anesthesia and providing critical care medicine in an austere environment presents a unique set of challenges. The supply of electrical power in austere environments is very often unavailable or unreliable. Portable generators often provide the only power that is available in the area. In our austere environment the generated power was described as “dirty.” “Dirty” in this context refers to wide swings in the voltage of the generated power that can permanently damage equipment plugged into the circuit. The electrical power supply in the United States is 120 V at 60-Hz frequency, and in Europe, Australia, and most of Africa and Asia, it is 230 V (range = 220-240 V) and 50-Hz frequency.¹¹ Plugging an electronic device rated for 120 V into a receptacle wired for 230 V results in burned-out circuitry. This occurred several times during the deployment.

In our case the IV infusion pumps arrived in-country inoperable and were unavailable for use when this casualty event occurred. Given our medical mission, having a more fundamental IV infusion plan in place that provided safe gravity infusions was essential for the team’s overall readiness. If our pumps had been operational, they would have required 120-V power to run, or at the very least, intermittent 120-V power to charge their internal batteries. Our pumps also required specific proprietary IV tubing, which our partner forces did not have. Because the patients were ultimately returning to partner forces, we initiated all infusions with standard IV tubing.

• **Control of Intravenous Flow by the Addition of a Flow Regulator.** Rapidly deployable surgical and resuscitation teams often rely solely on flow regulators for controlling gravity infusions. Flow regulators are devices added to the end of the IV tubing to improve control of the fluid flow compared with the in-line roller clamp. Two commonly available flow regulators require the solution container to be 51.2 cm (20 in) above the patient’s IV access site or 76.8 cm (30 in) above the midaxillary line. Flow regulator manufacturers caution healthcare providers about the need to verify the infusion rate by counting drops at regular intervals.^{12,13} These instructions are easily overlooked by providers who frequently

administer medication by titrating to effect. Vigilant observation and confirmation of drop count are necessary to ensure that there is correct delivery of the prescribed dose and a steady-state infusion. In reality and especially in austere environments, IV solutions are hung wherever a pole, hook, nail, or screw is available. Often the solution container is given to the closest available person to hold. By themselves, flow regulators do not improve the safety of gravity infusions without strict adherence to the manufacturer’s specifications. The use of the DripAssist infusion rate monitor in conjunction with a flow regulator provides 3 benefits: easy visual confirmation of the drop rate, calibration of the flow regulator to the specific patient situation and use, and alarm notification of a change in rate. If the DripAssist infusion rate monitor displays 25 mL/h with the flow regulator set at 50 mL/h, the flow regulator delivery rate is off by 50%. Therefore, the provider can use the information provided by the DripAssist to adjust the flow regulator to improve the accuracy of the flow regulator set points.

• **Gravity Infusions.** Gravity control of standard IV tubing is usually regulated by a roller clamp consisting of a wheel that rolls along an inclined plane through which the IV tubing runs.¹⁴ Several factors can affect gravity infusions to varying degrees: temperature, changes in the patient’s venous pressure, fluid viscosity, patient movement, IV catheter size, and tubing creep, which refers to the change in the compliance of the tubing as the tubing is compressed and released multiple times by the adjustment of the roller clamp. Regulating clamps, which are wheel or roller designed, are difficult to set and lack precise rate control. When the provider is counting drops and using the roller clamp to set the rate, inaccuracy of as little as 1 to 2 drops can introduce a 10% to 20% error rate in the total infusion time.¹⁵ Intravenous infusion errors can occur whether infusion is controlled by gravity or by infusion pump. Rooker and Gorard¹⁶ reported the infusion accuracy of 207 total IV bags 44% were given by “metered” IV infusion pumps and 56% by gravity infusion. According to the authors, 39% of the metered pump infusions infused accurately compared with only 21% of the gravity infusions. Han et al¹⁷ found that errors occurred in nearly one-fifth of continuous IV infusions regardless of whether gravity or pump administered, with errors in the rate of administration being most common. With gravity infusions, the probability of error increased as the duration of the infusion increased. The authors concluded that increased error rate over time was due to the need for frequent monitoring and adjustment of the roller regulator clamp.

• **Gravity Infusion Calculations.** Manufacturers provide IV tubing for a variety of drop rates. The drop rate is prominently displayed on the package and is typically 10, 15, 20, and 60 drops/mL. It is common to see this information written as gtt/mL, drop factor, or drip

factor on the packaging.¹⁸ The drop rate is a necessary variable in the calculation of the total infusion rate. Other variables include the patient's weight (where appropriate), infusion time, and the final concentration of the medication in the infusion.

The calculation for an IV infusion rate of 500 mL to be given over 20 minutes with 10 drop/mL tubing, using the formula, Infusion Rate (Volume (mL) ÷ Time (min)) x Drop Factor (drops/mL) = Flow Rate (drops/min), is as follows:

$$(500 \text{ (mL)} / 20 \text{ (min)}) \times 10 \text{ (drops/mL)} = 250 \text{ (drops/min)}.$$

A typical tranexamic acid infusion following the initial bolus would be 1 gm over 8 hours, or 480 minutes. If the tranexamic acid is placed in a 100 mL bag of NSS, the solution concentration is 1,000 mg in 100 mL or 10 mg/mL. The calculation is: (Volume to be infused (mL) x Drop Factor of the tubing) ÷ Time (min) to be infused, that is: (100 (mL) x 60 (drops/mL)) / 480 (min) = 12.5 drops/min.

To calculate the infusion rate for propofol, 100 µg/kg/min (100-mL bottle of propofol, 10 mg/mL) for an 85-kg patient using 60-drop tubing (drop factor of 60 drops/mL), the calculation is:

$$\begin{aligned} & (\text{Desired Dosage } (\mu\text{g/kg/min}) \times \text{Weight (kg)} \times 60 \text{ min/h}) \\ & \div \text{Medication Final Concentration } (\mu\text{g/mL}) = \text{mL/h} \\ & (100 \text{ } (\mu\text{g/kg/min}) \times 85 \text{ (kg)} \times 60 \\ & (\text{min/h})) / 10,000 \text{ } (\mu\text{g/mL}) = 51 \text{ (drops/mL) or } 51 \text{ (mL/h)} \end{aligned}$$

When using 10-, 15-, or 20-drop tubing, an additional calculation is necessary. For instance, when using 20-drop tubing, 20 drops equal 1 mL. Therefore, in the preceding example when using 20-drop tubing, the mL/h remains the same but the number of drops decreases:

$$\begin{aligned} 51 \text{ mL/h @ } 20 \text{ drops/mL} &= 1,020 \text{ drops/h} \\ 1,020 \text{ (drops/h)} / 60 \text{ (min/h)} &= 17 \text{ drops/min} \end{aligned}$$

Conversely, if the drops/min is known, then the µg/kg/min can be calculated. For example, the 85-kg patient has a propofol infusion running at 30 drops/min using 60 drop tubing. How many micrograms per kilogram per minute of propofol is the patient receiving?

$$\begin{aligned} & (X \text{ } (\mu\text{g/kg/min}) \times 85 \text{ (kg)} \times 60 \text{ (min/h)}) / 10,000 \\ & (\mu\text{g/mL}) = 30 \text{ drops/min or mL/h} \\ & (30 \text{ (mL/h)} \times 10,000 \text{ } (\mu\text{g/mL})) / (85 \text{ (kg)} \times 60 \text{ (min/h)}) \\ & = 58.8 \text{ } \mu\text{g/kg/min} \end{aligned}$$

• **A Review of Our Experience With the Infusion Rate Monitor.** The DripAssist infusion rate monitor mounts directly to the drip chamber of 10-, 15-, 20-, and 60-drop tubing by sliding up from the distal end of the chamber. The device is user-friendly with only 4 selector buttons. Once the device is turned on, the display screen prompts the user to select the size of IV tubing. Using the roller

clamp or a flow regulator, the user sets the desired rate in milliliters per hour or drops per minute. Total volume infused can also be displayed. The DripAssist monitor does not have a backlight display; however, there was no difficulty in seeing the display in low-level lighted areas. In our situation, we found that if there was enough light to count drops, there was enough light to see the DripAssist display. A 2-fold safety feature of the DripAssist is the audible alarm (80 dB at 10 cm) and flashing display screen, which are activated when a substantial change (±13%) occurs in the flow rate. The device is small at 12.8 × 6.1 × 2.8 cm (5 × 2.4 × 1.1 in), is lightweight at 106.4 g (3.8 oz), and runs on 1 disposable AA battery. We used our DripAssist intermittently for more than 100 days on the same battery. The manufacturer reports that a single battery provides approximately 360 hours of continuous use and that the flow rate is accurate within ±1% across the entire measurement range (4-400 drops/min).¹⁹

We rotated our one infusion rate monitor among the 7 infusions to ensure accurate flow rates. Although we did not perform a formal bench study of DripAssist's accuracy, the group did frequently evaluate volumes infused over set periods and found that our infusions rates were accurate. For example, a scheduled 8-hour infusion of tranexamic acid finished almost exactly at the 8-hour mark. Also, when propofol was infusing at 100 µg/kg/min (42 mL/h) on our 70-kg patient, the 100-mL bottle lasted about 2.5 hours. Ideally, we would have preferred to have several infusion rate monitors, but having even a single device had a major impact on infusion accuracy and patient safety. The device performed fully within the manufacturer's specifications. The medics and nurses reported the device was easy to use and faster to confirm the drop rate compared with counting drops with their watches or phones. The features of DripAssist also made confirmation of the infusion by a second team member extremely easy and convenient. Our FST deployed with multiple kinds of IV tubing (10-, 15-, 20-, and 60-drop tubing), and DripAssist worked well with all of them. The alarm feature was extremely beneficial in the face of our limited staffing. When patient 4 bent her arm, the ketamine infusion stopped, and DripAssist alarmed. On two other occasions, DripAssist notified the team when the infusion slowed because of a low level of fluid in the propofol glass bottle. The team informally looked at the benefit of DripAssist in conjunction with a flow regulator and found that the infusion rate monitor provided additional value to gravity infusion safety (improved accuracy in setting the infusion rate, monitoring the rate, and audible notification of changes in rate over time) compared with the flow regulator alone. During the 3 months we used the infusion rate monitor, we did not experience any negative issues regarding its performance.

Variable	DripAssist infusion rate monitor ¹⁹	MedSystem III infusion pump 2865B (without pole clamp) ²¹
Unit dimensions/cube, cm/cm ³ (in/cu in)	12.8 × 6.1 × 2.8 cm/216.3 (5 × 2.4 × 1.1/13.2)	20.2 × 15.4 × 5.4/1,630.5 (7.9 × 6 × 2.1/99.5)
Unit weight, kg (lb)	0.106 (0.24)	2.3 (5.1)
Unit price, \$	350	7,035
Protective case dimensions/cube, cm/cm ³ (in/cu in)	8.3 × 16.9 × 3.84/527.7 (3.25 × 6.6 × 1.5/32.2)	41.5 × 32.5 × 16.9/22,250.4 (16.2 × 12.7 × 6.6/1,357.8)
Travel case weight, kg (lb)	(0.09)	2.7 (6.1) with foam
Travel case price, \$	12	114

Table. Cube and Weight Comparison of One DripAssist Infusion Rate Monitor (Shift Labs) and One MedSystem III Multichannel Infusion System (CareFusion, Alaris)^a

^aThree DripAssist devices would be required to cover the operations of one 3-channel MedSystem III infusion system. The MedSystem III infusion pump requires proprietary tubing, which adds to the cost considerations for this device; DripAssist fits any commercially available (10-, 15-, 20-, or 60-drop) standard intravenous tubing.

• **Lessons Learned From Providing Intravenous Infusions Without Electronic-Controlled IV Pumps or Syringes.** From our experience, we learned the following:

1. In austere environments it was our experience that it was not *if* technology was going to fail, but *when* technology was going to fail. The ability to regulate a gravity infusion by counting drops should always be part of the IV infusion and medication administration plan.

2. Most anesthesia providers while providing a single anesthetic are comfortable with titrating to effect continuous medication infusions, without calculating the actual dosage delivered. In austere environments, providers can expect to manage multiple patients in preoperative and postoperative areas while simultaneously administering anesthesia. The display screen of the DripAssist infusion rate monitor provides easy visual confirmation of infusion rate information to all members of the team.

3. Consider diluting medications in a larger volume, thereby allowing for an increase in the drop rate. The slower the drop rate, the greater the chance of an inaccurate rate when counting drops without the infusion rate monitor.

4. The infusion rate of medications dispensed in nonvented glass bottles inherently slows over time as the bottle empties. Gravity infusions using glass bottles require extra vigilance.

5. Use of a carrier IV infusion when drop rates are low maintains a steady state of medication infusion.²⁰

6. The addition of a flow regulator and DripAssist infusion rate monitor to standard IV tubing improves the ability to make rapid flow rate changes and precise adjustments.

7. The DripAssist infusion rate monitor alarms (audible and visual) improve infusion rate safety compared with traditional gravity infusions.

8. Transportation to austere environments requires medical units to be packaged and mobile. Depending on

the mode of transportation, there may be major space and weight limitations. Whether it is air or ground transportation, a major consideration for inclusion is the metric (cube and weight) for every piece of equipment and all supplies. *Cube* is the cubic inches (or cubic centimeters) of the individual items or group of items. For a cube and weight comparison of the DripAssist infusion rate monitor and the standard FST IV infusion pump,²¹ see the Table. The standard FST IV infusion pumps are 3-channel; therefore, 3 DripAssist monitors would provide the infusion monitoring capability of 1 IV infusion pump. We recommend the addition of multiple DripAssist infusion rate monitors to the packing list of forward surgical or resuscitation teams.

Conclusion

The lessons learned in Syria to improve delivery of gravity IV infusions are relevant here in the United States, especially when we review the infrastructure devastation that hurricanes brought to Puerto Rico and Texas. The ability to deliver an accurate gravity infusion and to confirm dose and rate of medication delivered remains a fundamental nursing task. Basic mathematical calculations for drop and dosage rate need to be reviewed periodically to maintain the skill set. The DripAssist infusion rate monitor proved to be an invaluable tool for infusion rate verification as well as maintaining and monitoring gravity infusions during our deployment in an austere environment. Our experience demonstrated that these infusion rate monitors would prove equally useful in any situation using gravity infusions.

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DISCLOSURES

Shift Labs Inc donated a DripAssist infusion rate monitor and web-based training. The author has declared no other financial relationships with any commercial entity related to the content of this article. The author did not discuss off-label use within the article.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the men and woman of the 541st Forward Surgical Team (Airborne), Fort Bragg, North Carolina, for their professionalism, dedication, and support during Operation Inherent Resolve. The author thanks Shift Labs Inc for its generous donation of a DripAssist infusion rate monitor and web-based training. The author also thanks COL Vincent L. Leto, chief, Madigan Consolidated Education Division, Madigan Army Medical Center, Tacoma, Washington, and Mary Louise Marasco for their editorial review of the manuscript.