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A Review Evaluating Intravascular Access for High Volume Resuscitation: Can You Keep Up?

Puneet Mishra, MD • puneet.mishra@vumc.org

Jonathan P. Wanderer, MD • jon.wanderer@vumc.org

David A. Edwards, MD • david.a.edwards@vumc.org

Susan S. Eagle, MD • susan.eagle@vumc.org

Stephen P. Bruehl, PhD • stephen.bruehl@vumc.org

Matthew W. Semler, MD • matthew.w.semler@vumc.org

Kelly L. Mishra, MD • kelly.mishra@vumc.org

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Affiliation:
Vanderbilt University Medical Center

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Abstract

Anesthetists and anesthesiologists are frequently in the position of administering high-volume resuscitation in the setting of hemorrhage, hypovolemia, or vasodilatory shock. The ability to rapidly infuse intravenous (IV) fluid solutions differs vastly for different types and sizes of IV access. In patients who may require rapid large volume resuscitation, it is critical to understand the capacity of existing IV devices. Selecting the most appropriate IV access for patients can be paramount in preventing hypotension, end organ dysfunction, and even death. This article objectively reviews and compares the flow rates of commonly used central and peripheral intravenous devices to demonstrate the influence of catheter length and radius.

__Glossary of Terms:__

IV = intravenous

mL/min = milliliters/minute

Q = flow rate

n = viscosity

r = radius

l = length of tubing

PIVs = Peripheral Intravenous Catheters PICCs =

Peripherally Inserted Central Catheters CVCs = Central

Venous Catheters

RICs = Rapid Infusion Catheters

IO = Intraosseous

MAC = Arrow® Multi-lumen Access Catheter Fr = French

LAD = luer activating devices

SLIC = Single Lumen Infusion Catheter

INTRODUCTION

Choosing the most appropriate vascular access in patients with hypovolemic or vasodilatory shock is a critical decision for a perioperative or critical care clinician. While this is seemingly simple, a clinician must weigh the adequacy of existing intravenous (IV) access versus the time needed to place additional large-bore peripheral or central catheters. This is particularly critical in the time sensitive setting of acute hypovolemic shock due to severe hemorrhage in the perioperative and obstetrical arenas, where acute bleeding at rates over 500ml/min can occur.[1] Different forms of IV access have drastic differences in their ability to facilitate rapid fluid resuscitation ranging from maximum flow rates of 9.6 milliliters/minute (ml/min) to over 500ml/min. This manuscript collates information on several of the most common IV devices and presents it in tabulated and graphical format for easy reference. This information is meant to provide clinical decision support to the perioperative and critical care clinician.

DISCUSSION

Intravenous flow rates

The fundamental principles of Poiseuille's Law $(Q = \pi Pr^4/8nl)$ is critical in understanding the relationship among catheter length, radius, and flow rates for laminar flow. Poiseuille's Law states that flow rate *(Q)* is proportional to the pressure gradient along the IV tubing and inversely proportional to the viscosity *(n)* of the fluid as well as the length of the tubing (*l*). Increased fluid viscosity and increased length of tubing result in decreased flow rate when pressure is held constant. Very importantly, *Q* is proportional to the IV catheter radius (r) to the fourth power. Therefore, increasing the radius of an IV catheter drastically increases and has the largest impact on the flow rate. The impact of changes in *r* and *l* on *Q*, account for the wide range of flow rates across IV devices. This concept is paramount for understanding why some forms of central access may be superior while other are inferior to peripheral access when rapid, high-volume resuscitation is warranted. The infographic in Figure 1 compares the flow rates of these IV catheters.

Although the radius and length of IV catheters are of critical importance, there are numerous other factors that can affect flow rates. These include viscosity of the fluid administered, the radius of delivery tubing, the height of the fluid above the patient, the addition of a pressure bag, the presence of a fluid warmer, and in line devices such as luer-activating devices (LADs) with one-way valves that can limit flow. For example, LADs can reduce the flow rates through a 16g PIV by 19-38%.[2] Placing a PA Catheter or Arrow® Single Lumen Infusion Catheter (SLIC) through the introducer port on an Arrow® Multi-lumen Access Catheter or an Arrow® 8.5 Fr introducer will also reduce the flow rate. This explains why there are certain clinical scenarios where the maximum flow rate may be less than the manufacturer published rates.[3,4] However, the general principles of Poiseuille's law still apply, and the comparison between the different devices remains constant.

Types of intravenous access

Choosing the most appropriate IV access requires consideration of many factors, such as the specific indication for placement, the length of time the access will be required, how quickly access is needed, medications infused, ease of placement, risks, and the possible need for rapid large volume resuscitation. There are numerous types of IV catheters encountered in the inpatient setting: peripheral intravenous catheters (PIVs), peripherally inserted central catheters (PICCs), non-tunneled central venous catheters (CVCs), tunneled CVCs, peripheral rapid infusion catheters (RICs), hemodialysis CVCs, implanted ports, and intraosseous (IO) catheters. This review summarizes the salient points regarding rapid volume resuscitation for the most encountered IV catheters in the hospital setting.

Central Venous Catheters (CVCs) exist in many forms and the decision of which type to place is multifactorial. Not all CVCs allow for the high flow rates required for rapid volume resuscitation. For example, a triple lumen catheter is relatively long in length and provides significantly lower flow rates than most PIVs (Figure 1, Table 1). In fact, the 18g port of a triple lumen catheter infuses at a max rate of 26 milliliters/minute (mL/min) which is less than a 20-gauge PIV with a max flow rate of 65 mL/min. Therefore, if selecting a CVC, an Arrow® Multi-lumen Access Catheter, Arrow® 8.5 Introducer, or Arrow® double lumen central line would be more appropriate for rapid volume administration since each port can allow for flow over 100mL/min. The Arrow® Multi-lumen Access Catheter and Arrow® 8.5 Introducer are capable of infusion rates over 500 mL/min and can be used with rapid infuser devices.

A large bore CVC is advantageous in the setting of hemorrhage, and clinicians should weigh potential risks. These risks include time needed for placement, vascular injury, and central line associated blood stream infections. The risks should be balanced against the need for rapid infusion and administration of drugs such as vasopressors that can be caustic when infused peripherally.

Peripherally Inserted Central Catheters (PICCs) provide more durable and dependable IV access for patients with limited peripheral access and those needing long-term infusions. PICC lines are both small in diameter and long in length (three times longer than the next longest catheter); therefore, flow rate is slow at ~10 mL/min (Figure 1). PICC lines have very limited utility in patients needing high-volume resuscitation.

Rapid Infusion Catheters (RICs) are large bore, short, peripherally inserted catheters that allow for high flow rates. Most placed in the operating room environment, RICs are typically inserted in the antecubital vein, using the Seldinger technique. The large diameter (7 Fr and 8.5 Fr) and short length allow for rapid volume resuscitation up to 572 mL/min (Figure 1, Table 1). Even though RICs are superior to PIVs for large volume resuscitation, it is important to note that RICs require extra vigilance because high-volume peripheral infiltration and extravasation can occur rapidly and compromise vascular flow in the affected limb leading to compartment syndrome.[5,6]

Peripheral Intravenous Catheters (PIVs) are the most common IV access, primarily because the superficial nature of peripheral veins often allows for simpler and less traumatic access. There are several PIV catheter lengths, but flow rate primarily depends on the gauge. Furthermore, the relatively short catheter length of PIVs favors fast flow rates. The rate of a free-flowing crystalloid infusion ranges from 65 mL/min in a 20-gauge PIV to 325 mL/min in a 14-gauge PIV (Figure 1).

CONCLUSION

The purpose of this review and the included infographic and table is to objectively compare the flow rates of the IV catheters commonly used in the hospital setting. This information can help clinicians make an informed decision when choosing an IV catheter. Figure 1 illustrates that central venous access is not always superior to peripheral access when it comes to maximum flow rates. We argue that in the setting of acute hemorrhagic shock, one 16g peripheral IV is more effective than a triple lumen CVC. If very rapid fluid resuscitation is required, only the Arrow® Multi-lumen Access Catheter, Arrow® 8.5 Fr introducer, 7.0 Fr or 8.5 Fr RIC, and 14g PIV can provide resuscitation at rates over 300mL/min and can be considered true large bore access. 16g PIVs and double lumen central lines can provide rates over 200mL/min and thus serve as moderate sized IV access. Importantly, the maximum flow rates for triple lumen central lines, PICCs, and 20g PIVs are well under 100mL/min and cannot be considered adequate access if rapid volume resuscitation is required. Therefore, when choosing between the many different types of IV access that are available, it is critical to understand the Poiseuille's law principles and the integral role of catheter length and radius.

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TABLE 1. Flow Rate Comparison for IV Devices from Manufacturers

IntravenousAccessDevice	Flow (ml/min)	Flow (L/hr)	Time to infuse1L (minutes)
CENTRALVENOUSCATHETERS(CVC)			
Arrow® Multi-lumenAccessCatheter(MAC)			
9Frdistallumen	507	30.42	1.97
12Frproximallumen	199	11.94	5.03
Combined	706	42.36	1.42
Arrow® 8.5FIntroducer(Cordis)	500	30	2
DoubleLumenCVC			
Lumen1(14 g)	127	7.62	7.87
Lumen2(14 g)	100	6	10
Combined	227	13.62	4.41
TripleLumenCVC			
Lumen1(16 g)	53	3.18	18.87
Lumen2(18 g)	26	1.56	38.46
Lumen3(18 g)	27	1.62	37.04
Combined	106	6.36	9.43
PeripherallyInsertedCentralCatheter(PICC)	9.6	0.58	100
PERIPHERALRAPIDINFUSIONCATHETERS(RIC)			
8.5 Fr RIC	572	34.32	1.75
7 Fr RIC	500	30	2
PERIPHERALINTRAVENOUSCATHETERS(PIV)			
14 g PIV	325	19.5	3.08
16 g PIV	215	12.9	4.65
18 g PIV	110	6.6	9.09
20 g PIV	65	3.9	15.38

Flow rates for IV devices obtained from manufacturers in mL/min, L/hr, and time to infuse one liter of saline in minutes. CVC = Central Venous Catheters, RIC = Rapid Infusion Catheters, PICC = Peripherally Inserted Central Catheter, PIV = Peripheral Intravenous Catheter. Rates are based on 100 cm height gravity flow rates. Some resources may quote slight variations in flow rate, and this may be dependent on the testing conditions or slight variations in lengths for different brands of PIVs.

FIGURE 1. A Visual Comparison of Intravenous Catheter Type and Flow Rates
Rates obtained from manufacturers, found on packaging [Arrow® Multi-lumen Access Catheter (MAC)[7], Arrow® 8.5 Introducer, Arrow® double lumen central line, Arrow® triple lumen central line, Arrow® peripherally inserted central access (PICC)8, Arrow® 7.0 french and 8.5 french rapid infusion catheter (RIC), Jelco® peripheral intravenous catheters (PIV)]. [9] Sizes (radius, length) are all proportional and scaled. Arrow width is proportional to flow. Rates are based on 100cm height gravity flow rates. Some resources may quote slight variations in flow rate, and this may be dependent on the testing conditions or slight variations in lengths for different brands of PIVs.