The Role of the Hemodilution Ratio in Correlation to Blood Flow Velocity and the Impact of Venous Valves in Retrograde Blood Reflux

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▶ BACKGROUND

Interest in the investigation of the veins of the forearm regarding the impact of peripheral intravenous catheter (PIVC) was generated following completion of multimodal research applying a bundle of actions for placement and management of peripheral catheters. The highly successful PIV5Rights™ bundle study (Table 1) focused on VAD insertion in the forearm by a skilled clinician, use of ultrasound, a 22g 1.75" (3.85cm) catheter, an anti-reflux needleless connector, and a chlorhexidine (CHX) antimicrobial bordered securement dressing with checklist assessment; study protocol included consistent administration of saline flush, dressing changes every 7 days or as clinically indicated, and site assessment once or twice daily. It was determined that further investigation was needed into veins, venous valves, and forearm vein physiology associated with insertion, flushing, and management of PIV catheters. Performing detailed ultrasound assessment of the vasculature in the forearm was a method to provide answers to why the use of this insertion location was highly successful.

Table 1. Results from Steere and Moureau, JAVA 2019

Variable	Current State (n=94)	PIV5R (n=113)
Success Rate (therapy completed)	15%	89%
Dwell Time, Hours (mean ± SD, P<0.001)	29.6 ± 18.0	71.4 ± 58.8
Complications Rate (%, P<0.001)	40%	11%
Cost/Bed/Year (2018 USD)	$4,781	$1,405
Saving/Bed/Year (2018 USD)	–	$3,376

▶ PURPOSE

The purpose of this study was to establish a greater understanding of the human vasculature in association with fluid mechanics in veins above the hand and below the antecubital fossa (Figure 1). To accomplish this aim and accurately capture observational data of vascular anatomy, a high-resolution SIEMENS ACUSON S1000 Duplex Vein Mapping System was used by a Registered Vascular Technologist (RVT).

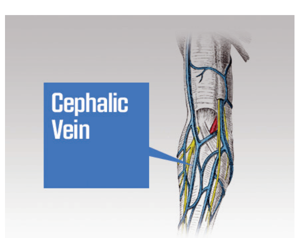

Figure 1. Veins of the forearm with a focus on the cephalic vein for PIVC insertion

Specific aims and study objectives

1. Collect observational data on blood flow velocities in veins of the forearm to evaluate and measure differentials, flow, and velocities associated with proximal and distal venous values for the four phases of venous valve position with and without normal saline infusion.

2. Provide visual recordings of blood flow, infusion flow rates, and flushing flow rates with normal saline through the catheter to demonstrate the changes in velocity.

▶ METHODS

This prospective in-vivo study was conducted following IRB approval #190307 with 10 consented Healthy Human Volunteers (HHV). The study captured high-resolution video images using color doppler recording the vein diameter, the velocity of blood flow and location of venous valves in the forearm (Figure 2). Using traditional computational fluid dynamic calculations, collected data were numerically analyzed for the velocity, volumetric blood flow, and hemodilution of infused fluids. Changes in blood flow velocity were recorded in association with pulse flushing.

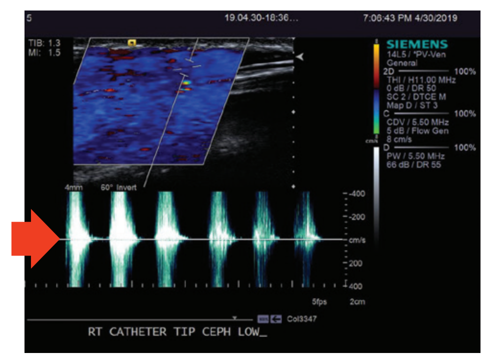

Figure 2. Example of a Vascular doppler Image with duplex measurement of a right forearm with a catheter placed in the lower cephalic vein. The arrow shows the blood flow velocity measured in frequency (cm/sec).

Study design and data collection outcomes

1. Blood flow velocity differentials occurring in the veins of the forearm, with and without catheter were measured.

2. Vein diameter in the forearm was determined, with and without a catheter and with and without a tourniquet.

3. Observational data were collected on location of venous valves and tip location in proximity (mm) to the venous valves.

4. Changes in blood flow velocity were recorded during pulsatile flushing of normal saline through the PIVC .

5. Volumetric blood flow rates and the corresponding hemodilution ration was calculated for each subject using an infusion flow rate of 250mL/hour or 4.17mL/minute.

HEMODILUTION RESULTS

Table 2. Results of Hemodilution Study with Forearm Cephalic Catheter Placement

Subject Number	Gender, Dom. Hand	Age	Height (inches) & Weight (lbs)	Forearm Cephalic Vessel Placement	Diameter with Catheter (cm)	Blood Velocity with Catheter (cm/sec)	Linear Blood Flow (cm/min)	Volumetric Blood Flow Rate (mL/min)	Infusion Rate 1500mg/ 250 mL/Hr	Hemodilution Ratio (>3mL/min)
7	Male, L	26	78/175	Upper 1/2	**0.12**	3.7	222	**2.51**	4.17	**0.60**
4	Female, R	32	60/130	Upper 1/2	**0.12**	6.1	366	**4.14**	4.17	**0.99**
8	Female, R	55	63/170	Upper 1/2	**0.24**	7.1	426	**19.27**	4.17	**4.63**
10	Female, R	60	65/145	Upper 1/2	**0.26**	2.6	156	**8.28**	4.17	**1.99**
6	Male, R	37	73/185	Upper 1/2	**0.29**	1.8	108	**7.13**	4.17	**1.71**
9	Female, L	56	67/180	Upper 1/2	**0.35**	3.6	216	**20.78**	4.17	**4.99**
2	Male, R	65	73/185	Upper 1/2	**0.36**	6.3	378	**38.48**	4.17	**9.23**
5	Male, R	54	79/290	Mid 1/2	**0.41**	8.6	516	**68.13**	4.17	**16.35**
3	Male, R	47	71/185	Upper 1/2	**0.45**	5.8	348	**55.35**	4.17	**13.28**
1	Female, R	43	59/134	Median A/C	**0.58**	3.0	180	**47.56**	4.17	**11.41**

Inputs:
Vein diameter (cm) = d
Blood velocity (cm/sec) = v
Linear flow = Lf
Volumetric flow rate = vfr

Conversions:
cm/sec to cm/min = v×60
Infusion rate = 250mL per hr ÷ 60 = 4.17

Formulas:
Lbf*π(3.1416)×d² ÷ 4 = vfr
vfr ÷ infusion rate = HDR

Table 2 includes the metrics used to calculate a 22g catheter to vein ratio and hemodilution ratio (vein size, blood velocity, volumetric blood flow rate). As an example, subject 10 had a 3:1 catheter to vein ratio, but low blood flow velocity at 2.6 cm/second, thus resulting in inadequate hemodilution (@1.99mL/min or <3mL/min). Alternatively, subject 8 also had a 3:1 catheter to vein ratio, but higher blood flow velocity at 7.1 cm/second, thus resulting in above adequate hemodilution (@4.63mL/min or >3mL/min).

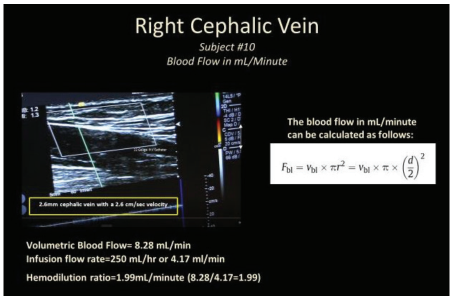

Figure 3. Hemodilution results shown for subject #10 (female, age 60, height 65", 145 lbs, upper forearm cephalic). Adequate catheter to vein ratio of 3:1, but inadequate hemodilution ratio of (<3mL/min).

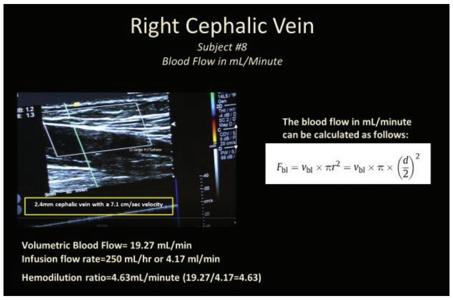

Figure 4. Hemodilution results shown for subject #8 (female, age 55, height 63", 170 lbs, upper forearm cephalic). Adequate catheter to vein ratio of 3:1, but above adequate hemodilution ratio of (>3mL/min).

RETROGRADE BLOOD REFLUX RESULTS

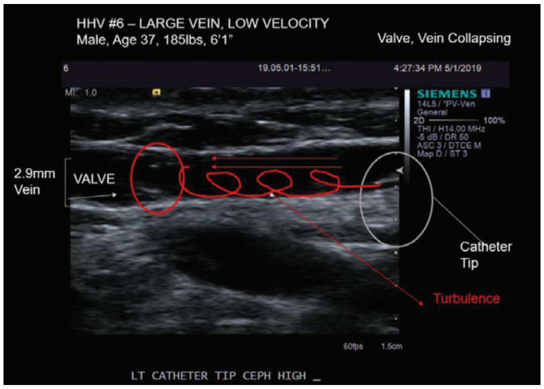

Figure 5. Subject #6 (male, age 37, height 73", 185 lbs, upper forearm cephalic) had a recorded vein size of 2.9mm and blood flow velocity @1.8cm/sec. A valve distal to the tip of the catheter was observed. During the flushing process, retrograde blood reflux, turbulence, and the vein collapsing were documented.

CONCLUSION

Results suggest that placement of a long peripheral IV catheter in the upper forearm cephalic vein may yield adequate flow and hemodilution. This data along with previous research suggests that PIVC use in the cephalic vein may help to reduce or eliminate IV complications such as chemical or mechanical thrombophlebitis which cause premature catheter failure. Application of these investigational principles may result in better outcomes and catheter longevity for patients requiring intravenous medication.

Limitations

Volunteer anatomical investigations have inherent limitations. Clinical implications tend to combine collected data and consensus opinion of the authors due to the small sample.

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