Venous pressure during intravenous regional anesthesia: Implications for setting tourniquet pressure

Borzoo Farhang, Alex C. Lesiak¹, Daniel J. Ianno², Hayk Minasyan², Adam B. Shafritz¹, Christopher M. Viscomi²
Department of Anesthesiology, University of Vermont Medical Center, Departments of ¹Orthopedic Surgery and ²Anesthesiology and Perioperative Medicine, University of Vermont College of Medicine, Burlington, VT, USA

Abstract

**Background and Aims:** Intravenous regional anesthesia (IVRA) is utilized for upper extremity surgery, but higher tourniquet pressure and longer inflation time increase the risk of soft tissue and nerve injury. We investigated the duration and magnitude of elevated venous pressure during IVRA to assess the possibility of safely lowering the tourniquet pressure during surgery.

**Material and Methods:** Twenty adult patients scheduled for distal upper extremity surgery were enrolled. An additional intravenous catheter was placed in the surgical arm connected to a digital pressure transducer for monitoring venous pressure. Venous pressure was recorded prior to IVRA and every 30 s after injection of local anesthetic (LA) until the completion of surgery.

**Results:** All 20 subjects completed the study without complication. Peak venous pressure was 340 mmHg in one patient which lasted for less than 30 s. Mean venous pressures fell below systolic blood pressure after 4.5 min in all cases except one. This patient had elevated venous pressures for 24 of 25 min of tourniquet time exceeding systolic blood pressure. The only statistically significant intraoperative factor associated with elevated venous pressure was elevated peak systolic pressure (P = 0.001).

**Conclusions:** We found that the mean peak venous pressure was below systolic blood pressure in only 14 of the 20 subjects, and the peak injection pressure exceeded 300 mmHg in one patient. Another patient’s venous pressure remained above systolic blood pressure for 24 of 25 min of tourniquet time. Current precautions to prevent LA toxicity may be insufficient in some patients and attempts to lower tourniquet pressures to just above systolic blood pressures soon after IVRA injection may result in toxicity, specifically if systolic pressure is elevated.

**Keywords:** IVRA, intravenous regional anesthesia, tourniquet pressure

Introduction

Intravenous regional anesthesia (IVRA) also known as Bier block is a common form of anesthesia for distal upper extremity surgery. It provides multiple advantages for the patient and operative team¹ such as the avoidance of general anesthesia, a bloodless field under tourniquet control, more rapid recovery and discharge from the hospital,² less postoperative nausea, and improved postoperative pain management.²³ The use of a pneumatic tourniquet is an essential part of IVRA; however, there are limitations on the safe use of this device. The pressure of the tourniquet is transmitted to the anatomic structures beneath it, and there is a legitimate concern for injury to nerves and soft tissue.⁴⁵

It is thought that the combination of direct compression from the tourniquet and ischemia distal to the inflated cuff may result in injury to nerves and other soft tissues.⁶ Lundborg demonstrated that after 8 h of ischemia, irreversible nerve...
damage is seen in animals, but in the presence of a tourniquet, these changes can be seen as early as 2 h.\textsuperscript{[6]} This emphasizes the importance of compression and the drive to decrease the inflation pressure and decrease tourniquet time in clinical practice. The severity of nerve injury varies considerably; it ranges from mild paraesthesia to complete paralysis. The contribution of tourniquet time to nerve injury is not well illustrated in reported cases (28–160 min in reported cases of complete paralysis); however, muscle injury is characterized as being associated with ischemia distal to the cuff and skin injury is reportedly due to inadequate padding under the cuff.\textsuperscript{[7]}

Since higher tourniquet pressures and duration greater than 2 h are thought to increase the risk of soft tissue injury,\textsuperscript{[8]} the tourniquet pressure is set at the minimum necessary to occlude blood flow to a limb (limb occlusion pressure). Additionally, during IVRA, when local anesthetic (LA) is injected, if venous pressures exceed tourniquet pressure, it can result in sub-tourniquet leakage of LA into the systemic circulation with associated risk of LA toxicity (primarily seizures and cardiac arrhythmias) as well as diminishing the effectiveness of the LA at the surgical site. Grice \textit{et al.}\textsuperscript{[11]} used radionucleotide-labeled IVRA injectate to demonstrate that four practices are necessary to minimize the likelihood of sub-tourniquet leakage of LA into the systemic circulation: injecting the LA over at least 2 min, use of a distal limb IV, Esmarch exsanguination (instead of gravity alone), and inflating the tourniquet to 300 mmHg.

Grice \textit{et al.}\textsuperscript{[12]} in a small sample of patients, showed venous pressures return to baseline over the 2–3 min following the completion of the IVRA injection. El-Hassan and Finnegan used older techniques to establish IVRA but showed venous pressure elevations declining within 3–5 min of completion of IVRA injection.\textsuperscript{[9,10]} Despite this limited evidence that venous pressures rapidly decline after IVRA injection, the common practice is to maintain tourniquet pressure at the previous set level which is usually 250–300 mmHg. However, there are commercially available tourniquet systems that vary tourniquet pressure based on systemic blood pressure.\textsuperscript{[11]}

This study was designed to evaluate the duration and magnitude of elevated venous pressure during IVRA in order to assess the possibility of safely lowering the tourniquet pressure prior to conclusion of surgery.

**Material and Methods**

After approval by the University of Vermont Institutional Review Board and obtaining written informed consent, 20 adult patients scheduled to undergo distal upper extremity surgery were enrolled in this single-arm, descriptive, prospective study. Inclusion criteria included men and women ages 18 and older who presented for carpal tunnel release surgery and other minor hand procedures scheduled for 45 min or less. Exclusion criteria included untreated/uncontrolled hypertension, immune deficiency, cardiovascular disease, chronic opioid use, history of phlebitis, history of nerve injury, and pregnancy.

Using aseptic technique, a 20G intravenous (IV) catheter was placed in the dorsum of surgical hand to be used for LA injection; next a second 20G IV catheter was inserted in the antecubital fossa and connected to a digital pressure transducer (Philips Medical, Andover, MA, USA) to monitor venous pressure. Cotton padding was placed around the mid upper arm, followed by the placement of a pneumatic tourniquet which was sized based on the diameter of the patient’s arm. The subject’s arm was raised for 30 s and wrapped tightly with an Esmarch bandage, beginning at the hand and extending to the distal end of the tourniquet. Next, the tourniquet was inflated to 300 mmHg and the Esmarch bandage was removed. Injection of LA was standardized for all patients such that through the IV cannula in the subject’s hand, 40 mL (females) or 50 mL (males) of LA was injected over 2 min via a 60-mL syringe. Venous pressures were recorded at time zero, defined as just prior to injection, then every 30 s until the conclusion of the surgical procedure or when venous pressure fell below 40 mmHg; At the conclusion of the procedure, the tourniquet was deflated and IV cannula was removed.

Using SPSS 23 software (SPSS Inc., Chicago, IL, USA), demographic data were compared between samples and analysis performed with one sample Chi-square and one sample Kolmogorov–Smirnov test.

**Results**

All 20 subjects, age 19–75, completed the study without complication; as shown in Table 1, no associations were noted between patients’ height, BMI, age, or history of hypertension with venous pressures using one sample Kolmogorov–Smirnov test or one sample Chi-square test.

The mean tourniquet time was 21 min (range 16.5–41.5 min). As seen in Figure 1, peak venous pressures were 340 and 248 mmHg in two subjects, which exceeded the systolic blood pressures by 190 and 130 mmHg, respectively (red star). The mean venous pressure fell below systolic blood pressure by 4.5 min postinjection in all cases except in one, whose venous pressure remained above systolic blood pressure for the entire surgical procedure of 25 min (blue star).

As seen in Figure 2, mean peak venous pressure was 75 mmHg, which occurred at 1.5 min after completion of the injection. Mean peak venous pressures were lower.
| Patient | Elevated venous pressure | Age (years) | History of hypertension | Body mass index | Height (cm) | Weight (kg) | Peak venous pressure (mmHg) | Peak systolic blood pressure (mmHg) | Mean systolic blood pressure (mmHg) | Peak injection pressure (mmHg) |
|---------|--------------------------|-------------|-------------------------|----------------|-------------|-------------|----------------------------|---------------------------------|---------------------------------|----------------------------------|
| 1       | Yes                      | 50          | No                      | 24.4           | 188         | 86.2        | 248                        | 123                             | 118.3                           | 230                              |
| 2       | No                       | 52          | Yes                     | 31             | 175         | 95.3        | 76                         | 143                             | 133                             | 51                               |
| 3       | No                       | 30          | No                      | 19.3           | 178         | 61          | 62                         | 109                             | 107                             | 104.8                            |
| 4       | No                       | 38          | No                      | 29.2           | 160         | 74.8        | 71                         | 107                             | 107                             | 107.5                            |
| 5       | Yes                      | 49          | Yes                     | 37.3           | 178         | 117.9       | 131                        | 140                             | 132.2                           | 125                              |
| 6       | Yes                      | 54          | Yes                     | 22.3           | 180         | 72.6        | 130                        | 140                             | 116.3                           | 47                               |
| 7       | No                       | 29          | No                      | 36.3           | 180         | 117.9       | 74                         | 120                             | 117.4                           | 45                               |
| 8       | No                       | 60          | Yes                     | 25.8           | 168         | 72.6        | 57                         | 121                             | 116.3                           | 31                               |
| 9       | Yes                      | 75          | No                      | 26.96          | 172.1       | 79.8        | 162                        | 108                             | 100.3                           | 88                               |
| 10      | No                       | 71          | Yes                     | 22.3           | 180         | 72.6        | 94                         | 143                             | 120.4                           | 83                               |
| 11      | No                       | 66          | Yes                     | 25.2           | 163         | 66.7        | 45                         | 153                             | 149                             | 29                               |
| 12      | No                       | 19          | No                      | 19.7           | 189         | 70.3        | 105                        | 134                             | 127.6                           | 69                               |
| 13      | No                       | 31          | No                      | 20.2           | 168         | 56.7        | 71                         | 124                             | 117.2                           | 64                               |
| 14      | No                       | 26          | No                      | 23.2           | 163         | 61.2        | 83                         | 135                             | 125.3                           | 67                               |
| 15      | Yes                      | 38          | Yes                     | 26.3           | 165         | 71.7        | 69                         | 148                             | 138.3                           | 69                               |
| 16      | Yes                      | 44          | Yes                     | 25.8           | 170         | 74.8        | 340                        | 150                             | 150                             | 78                               |
| 17      | No                       | 71          | Yes                     | 20.6           | 145         | 43.1        | 115                        | 157                             | 148.5                           | 67                               |
| 18      | No                       | 67          | No                      | 20.6           | 155         | 49.4        | 52                         | 138                             | 130.8                           | 35                               |
| 19      | Yes                      | 60          | No                      | 31.7           | 163         | 83.9        | 175                        | 125                             | 120.4                           | 175                              |
| 20      | No                       | 45          | No                      | 27.6           | 168         | 77.6        | 89                         | 130                             | 126.2                           | 89                               |

| Test     | One sample Kolmogorov-Smirnov | One sample Kolmogorov-Smirnov | One sample Kolmogorov-Smirnov | One sample Kolmogorov-Smirnov | One sample Kolmogorov-Smirnov | One sample Kolmogorov-Smirnov | One sample Kolmogorov-Smirnov |
|----------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| P        | >0.05                         | >0.05                         | >0.05                         | >0.05                         | 0.001                         | 0.001                         | >0.05                         | 0.001                         |
than systolic blood pressures in 14 out of 20 subjects. The average time for the mean venous pressure to fall to below 40 mmHg and remain below 40 mmHg was 11 min 30 s (range 0–20 min).

In all cases, IVRA was successful, there was no evidence of tourniquet pain requiring intervention, there was no clinical evidence of LA systemic toxicity in any of the subjects with elevated venous pressures, and there was no evidence of soft tissue injury from tourniquet or any other complications.

As seen in Table 1, there were no patient demographics associated with elevated venous pressures; however, presence of systolic hypertension during the procedure as defined as systolic blood pressure above 140 mmHg was associated with increased risk of elevated venous pressure \((P = 0.001)\). Additionally, despite standardization of injection time and syringe for injection of LA, patients with elevated injection pressures were more likely to have elevated venous pressures during the procedure \((P = 0.001)\). Figure 3 shows the relationship of systolic blood pressure and venous pressure for individual patients whose venous blood pressure exceeded systolic blood pressure at any point during the procedure.

**Discussion**

This study was designed to assess the venous pressure changes with injection of LA during IVRA and any associated contributors to elevation of venous pressure in order to safely lowering tourniquet pressure to less than 300 mmHg. In this study, all tourniquets were set to stay at 300-mmHg pressure during the entirety of the IVRA procedure and there was no evidence of soft tissue injury in our small population of patients. However, in several reported studies, attempts have been made to optimize tourniquet pressure to minimize complications, such as limiting tourniquet pressure to less than 250 mmHg for less than 150 min in the upper extremity,\(^8\) which have been shown to be safe in several series of patients, with occasional modification of tourniquet pressure to approximately 100 mmHg above systolic blood pressure.\(^12\)

The tourniquet pressure during IVRA should rationally be determined by at least two factors. Initially, the tourniquet must be inflated to a level greater than the pressure that occurs in the veins during the anesthetic injection. Grice’s work suggested that a pressure of 300 mmHg combined with other injection safeguards minimized sub-tourniquet leakage of LA during and immediately after LA injection.\(^9\) As shown in Figure 1, there is significant variability in venous pressure after injection of LA. In this study, two subjects’ peak venous pressures were 340 and 248 mmHg. Even though this study was not powered to assess the risk of LA toxicity, a peak venous pressure of 340 mmHg with a tourniquet pressure of 300 mmHg implies that some sub-tourniquet leakage of LA had occurred;
nevertheless, this was clinically insignificant due to the short duration of elevated venous pressure as well as lack of clinical evidence of systemic LA toxicity in the patients. However, presence of elevated blood pressure during the procedure as defined as systolic blood pressure above 140 mmHg was associated with elevated peak venous pressures during the procedure [Table 1]. This association, though not evident in all patients, may serve as a warning sign prohibiting decrease of tourniquet pressure if planned.

After the LA diffuses out of the veins and into the soft tissues, venous pressure falls. Theoretically, the tourniquet pressure must be greater than systolic arterial blood pressure or venous pressure (whichever is higher) to prevent leakage of LA into the systemic circulation. In a typical procedure under IVRA, systolic blood pressure is frequently measured, but venous pressure is unknown. A common clinical practice is to leave tourniquet pressure at the initial 250–300 mmHg for the entire operation, independent of systolic blood pressure. Nevertheless, our data demonstrate that there is no direct correlation between venous pressure and arterial blood pressure; therefore, it is not safe to decrease tourniquet pressure soon after injection of LA using arterial blood pressure as a guide, as evidenced by one of our subjects’ venous pressure that remained significantly above systolic blood pressure for nearly the entire time the tourniquet was inflated. While all other subjects exhibited a mean venous pressure which had fallen below systolic blood pressure at 4.5 min postinjection, the one patient with persistently elevated venous pressure would have been at an increased risk for LA toxicity with the lowering of tourniquet pressure to just above systolic blood pressure.

**Conclusion**

Venous pressures above 300 mmHg may occur during LA injection for IVRA, despite adhering to published clinical practice recommendations to minimize peak venous pressures. Thus, the possibility of systemic toxicity of LA remains. In addition, lowering the tourniquet pressure to marginally above systolic blood pressure several minutes after LA injection may be associated with increased risk of LA toxicity, as 30% of our patients had peak venous pressures above systolic blood pressure (albeit for a short duration) and one patient had venous pressures above systolic pressures for nearly the entire duration of surgery.

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**Conflicts of interest**
There are no conflicts of interest.
References

1. van Zundert A, Helmstädt A, Goerig M, Mortier E. Centennial of intravenous regional anesthesia. Bier’s block (1908-2008). Reg Anesth Pain Med 2008;33:483-9.
2. Brown EM, McGriff JT, Malinowski RW. Intravenous regional anaesthesia (Bier block): Review of 20 years’ experience. Can J Anaesth 1989;36:307-10.
3. Chan VW, Peng PW, Kaszas Z, Middleton WJ, Muni R, Anastakis DG, et al. A comparative study of general anesthesia, intravenous regional anesthesia, and axillary block for outpatient hand surgery: Clinical outcome and cost analysis. Anesth Analg 2001;93:1181-4.
4. Chong AK, Tan DM, Ooi BS, Mahadevan M, Lim AY, Lim BH, et al. Comparison of forearm and conventional bier’s blocks for manipulation and reduction of distal radius fractures. J Hand Surg Eur Vol 2007;32:57-9.
5. Guay J. Adverse events associated with intravenous regional anesthesia (Bier block): A systematic review of complications. J Clin Anesth 2009;21:585-94.
6. Lundborg G. Structure and function of the intraneural microvessels as related to trauma, edema formation, and nerve function. J Bone Joint Surg Am 1975;57:938-48.
7. Pedowitz RA, Gershuni DH, Fridén J, Garfin SR, Rydevik BL, Hargens AR. Effects of reperfusion intervals on skeletal muscle injury beneath and distal to a pneumatic tourniquet. J Hand Surg Am 1992;17:245-55.
8. Drolet BC, Okhah Z, Phillips BZ, Christian BP, Akelman E, Katarincic J, et al. Evidence for safe tourniquet use in 500 consecutive upper extremity procedures. Hand (NY) 2014;9:494-8.
9. El-Hassan KM, Hutton P, Black AM. Venous pressure and arm volume changes during simulated Bier’s block. Anaesthesia 1984;39:229-35.
10. Finnegan BA, Bukht D, Strunin L. Venous pressures in simulated Bier’s block. Anaesthesia 1984;39:1149-50.
11. Fitzgibbons PG, Digiovanni C, Hares S, Akelman E. Safe tourniquet use: A review of the evidence. J Am Acad Orthop Surg 2012;20:310-9.
12. Grice SC, Morell RC, Balestrieri FJ, Stump DA, Howard G. Intravenous regional anesthesia: Evaluation and prevention of leakage under the tourniquet. Anesthesiology 1986;65:316-20.