Compressed air injection technique to standardize block injection pressures

[La technique d'injection d'air comprimé pour normaliser les pressions d'injection d'un blocage nerveux]

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Purpose: Presently, no standardized technique exists to monitor injection pressures during peripheral nerve blocks. Our objective was to determine if a compressed air injection technique, using an *in vitro* model based on Boyle's law and typical regional anesthesia equipment, could consistently maintain injection pressures below a 1293 mmHg level associated with clinically significant nerve injury.

Methods: Injection pressures for 20 and 30 mL syringes with various needle sizes (18G, 20G, 21G, 22G, and 24G) were measured in a closed system. A set volume of air was aspirated into a saline-filled syringe and then compressed and maintained at various percentages while pressure was measured. The needle was inserted into the injection port of a pressure sensor, which had attached extension tubing with an injection plug clamped "off". Using linear regression with all data points, the pressure value and 99% confidence interval (CI) at 50% air compression was estimated.

Results: The linearity of Boyle's law was demonstrated with a high correlation, r = 0.99, and a slope of 0.984 (99% CI: 0.967–1.001). The net pressure generated at 50% compression was estimated as 744.8 mmHg, with the 99% CI between 729.6 and 760.0 mmHg. The various syringe/needle combinations had similar results.

Conclusion: By creating and maintaining syringe air compression at 50% or less, injection pressures will be substantially below the 1293 mmHg threshold considered to be an associated risk factor for clinically significant nerve injury. This technique may allow simple, real-time and objective monitoring during local anesthetic injections while inherently reducing injection speed.

Objectif *: Présentement, aucune technique normalisée ne permet de vérifier les pressions d'injection pendant les blocages nerveux périphériques. Nous voulions vérifier si une technique d'injection d'air comprimé, utilisant un modèle in vitro fondé sur la loi de Boyle et du matériel propre à l'anesthésie régionale, pouvait maintenir avec régularité les pressions d'injection sous les 1293 mmHg, pression associée à une lésion nerveuse cliniquement significative.*

Méthode *: Les pressions d'injection pour des seringues de 20 et 30 mL et diverses tailles d'aiguilles (18G, 20G, 21G, 22G et 24G) ont été mesurées dans un système fermé. Un volume défini d'air a été aspiré dans une seringue rempli de solution saline, puis comprimé et maintenu à des pourcentages variés pendant la mesure de la pression. L'aiguille a été insérée dans l'ouverture à injection d'un détecteur de pression muni d'une extension avec un bouchon d'injection en position fermée. La valeur de la pression et l'intervalle de confiance de 99 % (IC) pour une compression d'air à 50 % ont été évalués en utilisant une régression linéaire avec tous les points de données.*

Résultats *: La linéarité de la loi de Boyle a été démontrée avec une forte corrélation, r = 0,99 et une pente de 0,984 (IC de 99 % : 0,967-1,001) La pression nette générée sous une compression de 50 % a été de 744,8 mmHg avec un IC de 99 % entre 729,6 et 760,0 mmHg. Les diverses combinaisons de seringues et d'aiguilles ont présenté des résultats similaires.*

Conclusion *: En créant et en maintenant dans la seringue une compression d'air à 50 % ou moins, les pressions d'injection seront dans l'ensemble sous le seuil des 1293 mmHg associé à un facteur de risque de lésion nerveuse cliniquement significative. Cette technique peut permettre une surveillance simple, objective et en temps réel pendant les injections d'anesthésiques locaux tout en réduisant fondamentalement la vitesse d'injection.*

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THE incidence of nerve injury as a result of peripheral nerve blocks is reported to be low, varying from < 0.1% to 1%.[1,2] However, manifestations of block-related neurological injuries can be severe and may persist throughout a patient's life.[3] Several studies suggest that high pressure injection into the intraneural space is a major contributing factor to neurological injury during peripheral nerve blocks.[4–6] Considerable and prolonged elevation of intrafascicular pressure may cause membrane rupture or detrimentally interfere with the endoneurial microcirculation, leading to potentiation of local anesthetic toxicity.[5] A recent study showed that persistent motor deficits were observed in dogs injected intraneurally with pressures ≥ 25 psi [1293 mmHg from conversion factor 1 psi = 51.71 mmHg; 171.9 kPa (1psi = 6,894 Pa); 1.7 atm (1 psi = 0.068 atm)].[6] Fortunately, the intraneural injections that were not associated with high pressures did not result in persistent motor deficits, perhaps indicating that injection pressure may be a limiting factor.

A primary issue related to high injection pressures in clinical practice is that anesthesiologists often rely on a subjective "syringe feel" method to estimate what can be an abnormally high resistance to injection. In fact, a recent study showed that anesthesiologists vary widely in their ability to perceive an appropriate pressure and rate of injection during peripheral nerve blocks.[7] An additional concern is that injections are commonly performed by an assistant, while the anesthesiologist maintains the correct needle position, thus making injection pressures difficult to monitor objectively.

To address both issues of limiting and reducing the variability in pressures, it is desirable to develop a method of injection monitoring which will allow accurate prediction of whether injection pressures are at reasonable levels, while being both simple and conducive to real-time assessment for anesthesiologists. Our objective was to demonstrate that a compressed air injection technique (CAIT), using Boyle's law (confirmed with an *in vitro* experimental system) and typical regional anesthesia equipment, could consistently maintain injection pressures below 1293 mmHg.

Methods

A CAIT involves aspirating a set amount of air above a volume of injectate within a syringe, and subsequent compression and maintenance of this volume during injection to maintain pressure at a chosen level. Depending on the percent air compression, the pressure can be theoretically maintained at a level determined by Boyle's law (pressure × volume = constant). Using an *in vitro* model (Figure 1), CAIT was tested by measuring the pressure generated at the needle tip at various levels of air compression. The pressure was recorded using an infusion pump with an in-line pressure sensor (Asena® CC-MKIII, ALARIS™ Medical UK Ltd., Basingstoke, UK). Saline-filled syringes (10 mL, 20 mL and 30 mL; BD, Franklin Lakes, NJ, USA) and insulated needles (22G × 50 mm, 21G × 100 mm, 24G × 25 mm, 20G × 150 mm and 18G × 38.1 mm; B. Braun Medical Inc., Bethlehem, PA, USA), in all possible combinations, were connected. The needle was inserted into an injection port (Injection site, Interlink, BD, USA) which was connected in-series with the pressure sensor and extension

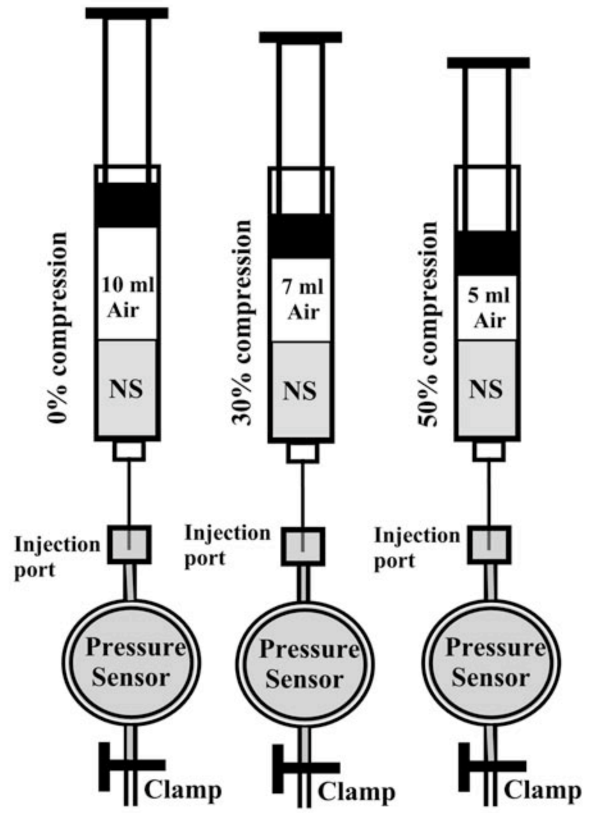

FIGURE 1 Schematic drawing of testing model for compressed air injection technique (CAIT)
Initially, a predetermined volume of air (10 mL) was aspirated into the syringe above 10 mL normal saline (NS). The air was subsequently compressed to pre-determined percentages (only 30 and 50% shown here). Generated pressures were recorded from the needle tip via a pressor sensor with clamped extension tubing.

tubing clamped to the "off" position (i.e., the system was closed). A set volume of air (10 mL) was aspirated into the syringe and then compressed and maintained at various percentages while pressure measurements were recorded (Figure 1). The compression level was maintained for several seconds to allow the pressure to equilibrate. The procedures were performed in duplicate and the same procedure was repeated for both syringes with all five needle sizes.

Data analysis

The formula $P_{final} / P_{initial} = V_{initial} / V_{final}$ was plotted to show the linear pressure-volume relationship described by Boyle's law. ($P_{initial}V_{initial} = P_{final}V_{final}$; where $P_{initial}$ and $V_{initial}$ are initial pressure (atmospheric pressure) and volume, respectively; P_{final} and V_{final} are the final pressure (measured 'net' pressure + initial pressure) and final volume (remaining volume), respectively. In Edmonton, Alberta, where the experiment was conducted, atmospheric pressure is generally about 101.7 Pa or 762.8 mmHg (according to the web-based Weather Network; www.theweathernetwork.com). For ease of calculation and consistency, all calculations are based on one atmospheric pressure being equal to 760 mmHg. Using linear regression (Microsoft Office Excel 2003, Microsoft, Redmond, WA, USA) with all data points, the correlation coefficient and slope were calculated, and the pressure value and 99% confidence interval (CI) at 50% compression was estimated. The 50% compression level was chosen for practical ease and because 60% compression would theoretically cause pressures close to or exceeding 1200 mmHg. Additionally, the pressure values at 50% compression had to be calculated due to the nature of manual compression, which did not consistently achieve 50% compression in all cases.

Results

The experiment (Figure 2) demonstrated a linear relationship, with r = 0.99 and a slope of 0.984 (99% CI: 0.967–1.001), between the pressure generated and the volume of compressed air in the syringe. At 50% air compression (compressing a total volume of air from 10 mL to 5 mL) the net pressure generated above atmospheric pressure, using the calculated slope and linear regression for all data points, was 744.8 mmHg (99% CI: 729.6–760.0 mmHg). The various syringe/needle combinations had similar results, as shown in Figure 2 and a plot of percent compression *vs* pressure (data not shown). The initial pressure reading at each compression level remained stable over the observation period lasting several seconds.

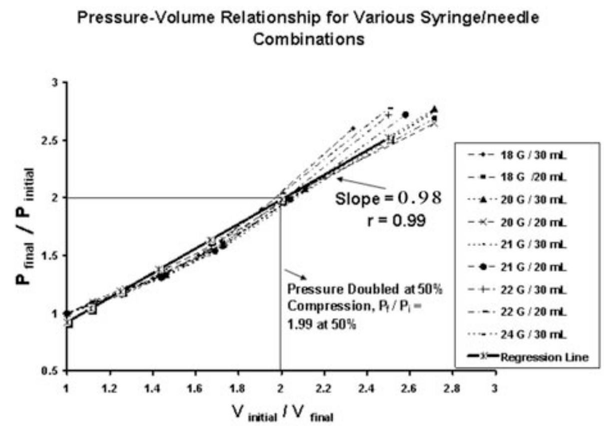

FIGURE 2 Pressure-volume relationships
Pressures (*Boyle's law :* $P_{final} / P_{initial} = V_{initial} / V_{final}$) in a closed system generated by compressing pre-determined volumes of air to set percentages in various syringe and needle combinations. Final pressure represents a net 'over pressure', as sensed by the nerve, measured from air compression and above the initial atmospheric pressure of 760 mmHg (i.e., absolute pressure would be approximately 1520 mmHg at 50% compression in ideal circumstances).

Discussion

Through observation of aspirated and compressed syringe air volumes, this *in vitro* study is the first to demonstrate the reliability of a systematic CAIT, with potential for standardizing local anesthetic injection pressures to ensure they are below a pressure threshold associated with clinically significant nerve injury. Using CAIT and Boyle's law, effectively doubling the syringe (atmospheric) pressure by an air volume compression of 50%, will ensure injection pressures (760.0 mmHg with 99% confidence) are well below the clinically significant threshold of 1293 mmHg. This injection technique could be used as a reliable and simple method to limit and monitor pressures generated at needle tips during peripheral nerve blocks.

In this study, the closed system model was selected to confirm that Boyle's law applies to an *in vitro* system using common anesthesia supplies. The closed system acts similarly to an ideal system where there is no fluid movement, hence creating a static environment in which pressures can be measured with a reasonable degree of accuracy. The results demonstrate that reducing gas volume by 50% effectively doubles the pressure and each syringe/needle combination performed similarly, with minimal variability in the recorded pressures. It is noteworthy that the closed system may approximate a high pressure intraneural injection scenario. Within certain compartments, only small fluid volumes may be injected, particularly intrafascicularly, due to limited space and a relatively low rate of pressure dissipation within the endoneurium.[5]

Theoretically, the pressure (approximated at the needle tip) should reach and maintain twice the atmospheric pressure at 50% compression. Since the absolute pressure would be approximately two atmospheres (1520 mmHg) the net "over pressure" recorded by the sensor (and theoretically 'felt' by the nerve) should be approximately 760 mmHg. Our results agree reasonably well with this assumption, as the net pressure at 50% compression was 744 mmHg. The key advantage of this technique's standardized pressure of 744 mmHg is the potential to prevent rapidly escalating peak pressures and thus reduce the risk of attaining the high opening pressures (1293 mmHg) associated with clinically significant nerve injury after intraneural injections.[6] Clearly, the 50% compression technique will not guarantee avoidance of the lower pressures (11 psi; 569 mmHg) associated with apparently uneventful intraneural injection. Although such low pressure intraneural injections seem to be clinically insignificant, the extent and outcome of nerve injury associated with low pressure intraneural injections remains unknown and warrants further investigation. Perineural injection pressures have been shown to result in pressures of approximately 200 mmHg (4 psi) in dogs; suggesting that 50% compression may exceed desired thresholds in some cases, while remaining adequate for most injections.[6] The above considerations suggest that a limit of 50% compression should not be exceeded with lower compression values being appropriate for most perineural injections.

The syringe and needle sizes were selected on the basis of clinical relevance. With current localization techniques, including ultrasound and nerve stimulation, either 20 or 30 mL syringes are typically used. Needle size varies according to the type of block being performed, location of the nerve, and operator preference. As the size of both needles and syringes has been associated with many-fold differences in pressure readings when using the syringe-feel injection method,[7] it was necessary to evaluate various combinations to confirm that CAIT is reliable for a range of needle and syringe sizes. Each syringe/needle combination elicited similar results throughout the experiment, although the relatively small sample size of each combination precluded estimation of variance analysis between samples. The sample size was adequate for demonstrating the utility of a basic law of physics. The observation of similar results for all combinations was important to generate the necessary data for linear regression, and calculate the slope and estimate the mean pressure and 99% CI at 50% air compression.

Two limitations of this technique include potential variability of injection pressures and the possible risk of air injection. Accurate aspiration of set volumes of air and reading the syringe for volume changes will be essential for correct interpretation of injection pressures. However, even moderate variations in injection pressure, as observed in our experimental model involving manual air withdrawal and compression, would not significantly change the overall results, as pressures at 50% compression (upper CI of 760 mmHg) would still be well below the critical pressure of 1293 mmHg. This technique is further safeguarded as the injection pressure limit of 1293 mmHg has been established in dogs, and it is evident that there is species variation (likely related to nerve size), as shown with limits of 300–750 mmHg in rabbits.[5] Additionally, limiting the extent of compression to 50% should be clinically relevant, as lower pressures should be easily maintained with most perineural needle positions. Perhaps a more critical issue to consider is the potential for air injection with the possibility of venous air embolism. One study identified embolic complications related to the use of an air loss-of-resistance technique associated with epidural placement.[8] Although concerns are real if a sufficient volume of air reaches the venous circulation (as with spinal epidurals),[9] the inherent air-volume monitoring requirement of this technique should safeguard against any clinically significant air injection. Of note, the risk of air embolism from CAIT would be similar to that of another commonly used technique incorporating an air bubble with loss-of-resistance to saline.[10]

In summary, the ability to consistently and easily maintain injection pressures below a predetermined level suggests that CAIT may offer a simple and practical tool for monitoring and standardizing local anesthetic injections. By using CAIT (at 50% maximum compression), the ability to provide injection pressures well below a critical threshold of 1293 mmHg is reasonably assured. Clinical trials to evaluate the usefulness of this technique in the practice of anesthesia are warranted.

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