Intravenous regional analgesia with a forearm tourniquet

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Lidocaine 0.5 per cent in a dose of 2 mg·kg^{-1} was used for intravenous regional analgesia with the tourniquet cuff placed over the forearm. The level of tourniquet cuff pressure employed was the arterial "occlusion pressure" plus 50 mmHg. In 48 normotensive patients successful analgesia was achieved; in seven hypertensive patients, four were pain-free, but the other three required more lidocaine to achieve adequate analgesia. No toxic symptoms and signs were observed. Measurement of serum lidocaine concentrations in 12 patients confirmed the safety of the technique, although small leakage of lidocaine past the inflated forearm tourniquet was detected in some patients.

The technique of intravenous regional analgesia using a tourniquet consisting of two cuffs over the upper arm is a well-recognized procedure.[1] With the tourniquet being conventionally placed over the upper arm, a relatively high dose of local anaesthetic drug is required and occasionally systemic toxic reactions, manifested as convulsion, coma, cardiovascular and respiratory depression, and even cardiac arrest, have occurred.[2–4] Toxicity may be due to leakage past the tourniquet following injection, because of either tourniquet failure or build-up of excessively high venous pressure distal to the tourniquet.[5–7] Adverse reaction can also occur after release of the tourniquet if a large dose of local anaesthetic has been given.

Rousso *et al.*[8,9] demonstrated that when the tourniquet was applied to the forearm below the elbow satisfactory ischaemia of the hand and wrist could be obtained in 99 per cent of patients. They also showed that successful analgesia could be achieved in the majority of patients when bupivacaine was injected intravenously with use of a forearm tourniquet.[10] In their study, although a lower dose of bupivacaine (37.5–100 mg) was required compared with the conventional technique using an upper arm tourniquet (75–200 mg),[8] serum bupivacaine levels were not measured. In view of the possible cardiotoxicity of bupivacaine,[2] intravenous regional analgesia using bupivacaine can no longer be recommended. Use of an alternate local anaesthetic with less side effects would be more desirable.

We postulated that lidocaine in low doses might be a suitable substitute for bupivacaine. The purpose of the present study was to establish the efficacy of the technique of intravenous regional analgesia with a forearm tourniquet using reduced doses of lidocaine. Serum concentrations of lidocaine were measured in some of the patients studied, to determine the safety of the technique. Another objective was to determine the forearm tourniquet pressure levels required to produce arterial occlusion.

Key words
ANAESTHETIC TECHNIQUE: regional, intravenous;
ANAESTHETICS, LOCAL: lidocaine

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Methods

The study was conducted with the approval of the Ethical Committees, both of the Hong Kong University and Medical and Health Department, and the patients gave informed consent.

Fifty-five unpremedicated patients (23 male, 32 female), of ASA physical status class I or II, undergoing various elective operations on the distal forearm, wrist and hand were included (Table I). They were aged between 11 and 65 yr (mean 41.3 yr), and weighed from 33.2 to 83 kg (mean 56.3 kg).

Immediately before the start of anaesthesia arterial blood pressure was measured in the contralateral arm with a standard adult cuff using a mercury sphygmomanometer. An ultrasonic Doppler flow detector (Model 811, Parks Medical Electronics Inc., Oregan, U.S.A.) was positioned over the radial artery to measure the systolic blood pressure. Only in patients whose systolic pressure was found to be elevated was the diastolic blood pressure measured by auscultation over the brachial artery. Two pneumatic cuffs (Inflatomatic pneumatic tourniquet cuff, Zimmer Inc. International, U.S.A.), each 5 cm wide, were placed in series over padding on the forearm below

TABLE I Operative sites

Anatomical region	*Number of operations*
Lower forearm and wrist	22
Hand, at or proximal to metacarpo-phalangeal joint	23
Digits	10

the sphygmomanometer cuff. The proximal cuff was placed 5 cm distal to the medial epicondyle of the humerus. The circumference of the forearm at the upper border of the proximal cuff was measured. An automatic pneumatic tourniquet machine (Tourniquet Control Unit, Mk 2, OEC Orthopaedic Ltd., U.K.) was used for inflating the pneumatic cuffs. The gauge on the machine was calibrated against a mercury column before each operating session.[11]

"Occlusion pressure,"[12,13] the cuff pressure required to occlude the radial blood flow, was measured in the forearm and compared with the systolic blood pressure taken on the upper arm. This pressure was determined both for the proximal and distal pneumatic tourniquet cuffs.

Having found the occlusion pressures, the pneumatic cuffs were removed and placed in a similar manner over the forearm to be operated on. A 22-gauge teflon cannula was inserted into a vein over the dorsum of the hand. The limb distal to the proximal pneumatic cuff was exsanguinated by applying an Esmarch's bandage, starting from the finger tips. The proximal tourniquet cuff was then inflated to a pressure equal to the occlusion pressure plus 50 mmHg,[12] and the Esmarch's bandage was removed. Tourniquet failure was ruled out by observing the distal circulation. The calculated amount of 0.5 per cent preservative-free lidocaine solution (2 $mg \cdot kg^{-1}$ body weight) was injected through the intravenous cannula on the dorsum of the hand, over two minutes. The maximum amount injected was 25 ml (125 mg) even if the body weight indicated a higher dose. Thereafter onset of analgesia was tested by pinching the skin with a pair of Allis forceps, closing up to the first lock of its ratchet. If onset of analgesia was incomplete in the area of incision by ten minutes after injection, a further dose of 0.5 per cent lidocaine equivalent to 0.5 $mg \cdot kg^{-1}$ was given through the cannula and repeated if necessary after a further five minutes. The intravenous cannula was then removed and surgery commenced.

During the operation, if the patient complained of tourniquet discomfort, the proximal cuff was released after inflation of the distal cuff to a pressure equal to the occlusion pressure plus 50 mmHg.

After completion of surgery the tourniquet cuff was deflated quickly with no re-inflation. Close monitoring of the electrocardiogram, blood pressure and pulse was carried out during the operation and in the following 30 minutes in the recovery room. Thereafter blood pressure and pulse were observed hourly on the ward for six hours.

The time when pain sensation had recovered was noted. All patients were examined two weeks after the operation to detect any possible late complication arising from the technique.

In 12 randomly chosen patients venous blood samples were taken for estimation of lidocaine concentration from an indwelling intravenous catheter placed in the contralateral upper limb. Samples were taken before lidocaine injection, one minute after the completion of lidocaine injection, and at 1, 5, 15 and 30 minutes after release of the tourniquet. Serum samples were extracted by a method modified from the method of Narang *et al.*[14] High performance liquid chromatography was performed with extracts from 300 μL of serum. The coefficient of variation for between-run analysis at serum lidocaine concentrations of 0.19 $\mu g \cdot ml^{-1}$ and 1.01 $\mu g \cdot ml^{-1}$ was 8.4 and 7.4 per cent respectively. The lower limit of quantitation was 0.05 $\mu g \cdot ml^{-1}$.

Results

Analgesia rapidly set in after intravenous injection of lidocaine, being complete within five minutes in 76 per cent of the patients.

Forty-eight patients had normal blood pressure for their age; among them eight had body weight more than 62.5 kg and they received the maximum dose of 25 ml of 0.5 per cent lidocaine (125 mg). In all of the patients successful analgesia was achieved. However, mild venous congestion of the operative site was encountered in one patient.

Seven patients had blood pressures above 190/100 mmHg; none weighed more than 62.5 kg. Four patients were pain-free, but congestion of forearm veins was evident in two of them during operation. In the remaining three hypertensive subjects, two required an additional dose of 0.5 $mg \cdot kg^{-1}$ and the other an additional 1 $mg \cdot kg^{-1}$ lidocaine through the intravenous cannula in the isolated forearm before adequate analgesia was attained; venous congestion of the operative site was noted in one of these three patients.

Tourniquet time varied from 20 to 94 min (mean ± SD = 32 ± 9 min). In five patients (9.1 per cent), the distal cuff had to be inflated in order to relieve tourniquet discomfort from the proximal cuff.

Recovery of pain sensation was also rapid after release of tourniquet. Forty-five of the 55 patients (82 per cent) recovered sensation within 20 minutes.

No abnormal changes were seen in the electrocardiogram. Systolic arteial blood pressure fluctuated within a

TABLE II Serum lidocaine concentrations ($\mu g \cdot ml^{-1}$) in 11 patients given lidocaine $2 mg \cdot kg^{-1}$ for intravenous regional analgesia with a tourniquet over the forearm. Mean tourniquet time = 29.4 min (SD 7.4 min).

	Intravenous injection		*Time after tourniquet release (min)*			
	Before (n = 11)	*1 min after (n = 11)*	*1 (n = 7)*	*5 (n = 9)*	*15 (n = 9)*	*30 (n = 7)**
Range	0	0–0.85	0–1.00	0–1.55	0.35–1.45	0.25–1.20
Mean	0	0.26	0.39	0.68	0.75	0.70
SD	0	0.35	0.42	0.53	0.33	0.31

*Not every subject had blood drawn at all six sampling times.

relatively narrow range during the operation. The change was from −20 to +35 mmHg. Direct questioning did not reveal any toxic symptoms. Signs indicating toxicity or late complications arising from the technique were not encountered.

Eleven of the 12 patients whose venous lidocaine concentrations were measured received $2 mg \cdot kg^{-1}$ lidocaine. Their results are presented in Table II. Leakage of the drug past the pneumatic cuff into the systemic circulation prior to tourniquet release was found on six occasions. The concentrations observed were all very low. The highest lidocaine concentration was attained always after release of the tourniquet, usually at 15 minutes. In none of the patients did the lidocaine level exceed $1.6 \mu g \cdot ml^{-1}$. In one hypertensive subject (not included in Table II) who required $2.5 mg \cdot kg^{-1}$ in order to achieve analgesia, the highest lidocaine concentration attained was $1.8 \mu g \cdot ml^{-1}$, occurring at 15 minutes after tourniquet release.

The occlusion pressure as measured with both the proximal and distal cuffs over the forearm was always higher than the initial arm systolic blood pressure. The difference between proximal cuff occlusion pressure and systolic arterial pressure ranged from 5 to 105 mmHg (mean ± SD = 53 ± 22 mmHg); whereas that between distal cuff occlusion pressure and systolic arterial pressure ranged from 15 to 125 mmHg (mean ± SD = 67 ± 25 mmHg). Either of these values did not show any correlation with the initial systolic blood pressure measured over the upper arm, the coefficient of correlation being 0.01 and 0.11 respectively.

The circumference of the forearm at a point 5 cm distal to the medial epicondyle of the humerus varied from 18.5 to 28.5 cm (mean 23.5 cm). The difference between proximal cuff occlusion pressure and systolic arterial pressure did not bear any relation to this circumference (coefficient of correlation = 0.46).

Discussion

In all the 48 normotensive subjects, successful analgesia was achieved using a dose of no more than $2 mg \cdot kg^{-1}$ of 0.5 per cent lidocaine. This demonstrated the efficacy of the technique of intravenous regional analgesia with a forearm tourniquet using a low dose of lidocaine, comparable to the size of the bolus dose used for treating ventricular arrhythmias.[15] The safety of the technique was confirmed by absence of symptoms and signs of toxicity and by measurement of serum lidocaine concentrations. The maximum serum concentration attained was always below $2 \mu g \cdot ml^{-1}$, much less than the toxic concentration of $5 \mu g \cdot ml^{-1}$, which produces mild lidocaine toxicity.[16]

In the seven hypertensive subjects (blood pressure >190/100 mmHg), three showed venous congestion of the forearm below the tourniquet. Furthermore, three hypertensive patients required additional lidocaine in order to achieve analgesia for surgery.

Many hypertensive subjects have atherosclerosis, which might render complete occlusion of their blood vessels difficult to achieve by a pneumatic tourniquet. A small amount of seepage of blood past the tourniquet, through the nearly occluded atherosclerotic artery, might not be detectable by palpation or by an ultrasonic Doppler flow detector over the radial artery. This could account for the venous congestion seen in some of the hypertensive patients. Presence of an excessive quantity of blood in the vascular system beyond the tourniquet would cause dilution of the injected lidocaine and likely resulted in the inadequate analgesia with the initial $2 mg \cdot kg^{-1}$ dose. From the results of the present study it would appear that intravenous regional analgesia with a forearm tourniquet can not be recommended for hypertensive patients.

One important factor affecting the success of intravenous regional analgesia is the tourniquet pressure. The pneumatic cuffs we used had a width of 5 cm. This is much narrower than the standard adult sphygmomanometer cuff used for measuring blood pressure. As a narrow cuff is less able to transmit tourniquet pressure to blood vessels lying deep inside the limb,[17,18] this explains why the occlusion pressure was always higher than systolic arterial pressure. Variation in the amount of the component structures making up the limb (bone, muscle,

subcutaneous fat and other soft tissue) in different subjects accounted for the varying difference between occlusion pressure and systolic blood pressure; the same argument also explains the difference in occlusion pressures measured with the proximal and distal pneumatic cuffs.

An empiric formula that would yield an adequate pressure level for the forearm tourniquet could be derived as follows:

$$\text{Forearm tourniquet pressure} = \text{SAP} + \text{mean(OP–SAP)} + \text{SD(OP–SAP)} \times 3 + \Delta\text{SAP}$$

SAP = the preanaesthetic systolic arterial pressure measured on the arm; mean(OP–SAP) = the mean difference between forearm cuff occlusion pressure and SAP; SD(OP–SAP) = the standard deviation of the difference between occlusion pressure and SAP; ΔSAP = the maximum change in systolic arterial pressure during operation.

Based on the data from the present study, the suggested tourniquet pressure for the proximal forearm cuff is equal to SAP plus 155 mmHg; and that for the distal cuff, SAP plus 180 mmHg. Retrospectively, the tourniquet pressure calculated in this manner always was no less than the actual tourniquet pressure employed in the present study, namely, arterial occlusion pressure plus 50 mmHg.

Despite slow intravenous injection of the lidocaine over two minutes in an attempt to minimize abrupt elevations in venous pressure,[7,18,19] leakage past the properly functioning tourniquet still occurred in six of the 11 patients who received 2 mg·kg^{-1} and whose lidocaine blood levels were measured (55 per cent). This is similar to the leakage rate of 67.5 per cent reported by Kalso *et al.*;[20] in their patients the tourniquet was placed over the upper arm. Spread of lidocaine to the systemic circulation via intraosseous blood flow which is not affected by a tourniquet offers one possible explanation.[21]

An additional advantage noted in our study employing a forearm tourniquet was that some motor function of the long flexors and extensors of the wrist and hand were preserved. This proved to be very useful in certain operations such as tenolysis and fixation of hand fractures.

In conclusion, the technique of forearm intravenous regional analgesia as described, employing a low dose of 0.5 per cent lidocaine, provided successful analgesia in all 48 *normotensive* pattients. In spite of some leakage of lidocaine past the inflated forearm tourniquet the method was found to be safe.

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References

1 *Holmes C.* Intravenous regional analgesia, a useful method of producing analgesia of the limbs. Lancet 1963; 1: 245–7.

2 *Albright GA.* Cardiac arrest following regional anesthesia with etidocaine or bupivacaine. Anesthesiology 1979; 51: 285–7.

3 *Davies JAH, Gill SS, Weber JCP.* Intravenous regional analgesia using bupivacaine. Anaesthesia 1981; 36: 331.

4 *Heath ML.* Deaths after intravenous regional anaesthesia. Br Med J 1982; 285: 913–4.

5 *Rosenberg PH, Kalso EA, Tuominen MK, Linden HB.* Acute bupivacaine toxicity as a result of venous leakage under the tourniquet cuff during a Bier block. Anesthesiology 1983; 58: 95–8.

6 *Duggan J, McKeown DW, Scott DB.* Venous pressures generated during i.v. regional anaesthesia (IVRA). Br J Anaesth 1983; 55: 1158P-9P.

7 *Grice SC, Morell RC, Balestrieri FJ, Stamp DA, Howard G.* Intravenous regional anesthesia: evaluation and prevention of leakage under the tourniquet. Anesthesiology 1985; 63: A221.

8 *Rousso M, Wexler MR, Weinberg H, Magora F.* Regional anaesthesia for hand surgery. Prog Surg 1979; 16: 44–52.

9 *Rousso M, Wexler MR, Weinberg H, Vatashky E, Aronson B.* Subcutaneous ring anaesthesia in the prevention of tourniquet pain in hand surgery. Hand 1978; 10: 317–20.

10 *Rousso M, Drexler H, Vatashky E, Ashur H, Aronson HB.* Low i.v. regional analgesia with bupivacaine for hand surgery. Br J Anaesth 1981; 53: 841–4.

11 *Hallet J.* Inaccuracies in measuring tourniquet pressures. Br Med J 1983; 286: 1267–8.

12 *Reid HS, Camp RA, Jacob WH.* Tourniquet hemostasis. A clinical study. Clin Orthop 1983; 177: 230–4.

13 *Davies JAH, Hall ID, Wilkey AD, Smith JE, Walford AJ, Kale VR.* Intravenous regional analgesia. The danger of the congested arm and the value of occlusion pressure. Anaesthesia 1984; 39: 416–21.

14 *Narang PK, Crouthamel WG, Carliner NH, Fisher ML.* Lidocaine and its active metabolites. Clin Pharmacol Ther 1978; 24: 654–62.

15 *Gianelly R, Von Der Groeben JO, Spivack AP, Harrison DC.* Effect of lidocaine on ventricular arrhythmias in patients with coronary heart disease. N Engl J Med 1967; 277: 1215–9.

16 *Bromage PR, Robson JG.* Concentrations of lidocaine in the blood after intravenous, intramuscular, epidural and endotracheal administration. Anaesthesia 1961; 16: 461–78.

17 *Shaw JA, Murray DG.* The relationship between tourniquet pressure and underlying soft-tissue pressure in the thigh. J Bone Joint Surg 1982; 64A: 1148–52.

18 *El-Hassan KM, Hutton P, Black AMS.* Venous pressure and arm volume changes during simulated Bier's block. Anaesthesia 1984; 39: 229–35.

19 *Lawes EG, Johnson T, Pritchard P, Robbins P.* Venous pressures during simulated Bier's block. Anaesthesia 1984; 39: 147–9.

20 *Kalso E, Tuominen M, Rosenberg PH, Alila A.* Bupivacaine blood levels after intravenous regional anaesthesia of the arm. Reg Anaesth 1982; 5: 81–4.

21 *Cotev S, Robin GC.* Experimental studies on intravenous regional anaesthesia using radioactive lidocaine. Br J Anaesth 1966; 38: 936–40.

Résumé

La lidocaine 0.5 pour cent à des doses de 2 mg·kg^{-1} a été utilisée pour l'analgésie régionale intraveineuse avec tourniquet placé sur l'avant-bras. La pression du tourniquet utilisé était la somme de la pression d'occlusion de l'artère plus 50 mmHg. Chez 48 patients normotendus une analgésie a été acquise; chez sept patients hypertendus, quatre étaient soulagés de douleur, mais les trois autres ont requis plus de lidocaine pour une analgésie adéquate. Aucun signe ou symptôme de toxicité n'était observé. La mesure de la lidocaine sérique chez 12 patients a confirmé la sécurité de la technique même si des légères fuites de la lidocaine à travers le tourniquet gonflé autour de l'avant-bras étaient détectées chez certains patients.