Quantitative evaluation of tourniquet leak during i.v. regional anaesthesia of the upper and lower limbs in human volunteers

A.-C. Hoffmann, E. Van Gessel, Z. Gamulin, J.-E. Rysér and A. Forster

Summary

Although it is accepted that during i.v. regional anaesthesia (IVRA) local anaesthetic can leak under the tourniquet into the systemic circulation, no published study has evaluated this leak quantitatively. In volunteers, during two random sessions, we have simulated IVRA using standard techniques with a radiolabelled compound which is chemically similar to lignocaine and has comparable tissue distribution (0.1 mg of HIDA labelled with 100 µCi of 99mTc in 40 ml of saline). The decrease in radioactivity was measured with a gamma camera for the 20 min of tourniquet inflation and for the 20 min of washout after cuff deflation. While the tourniquet was inflated, the leak for the lower limb (mean 29 (SD 8) %) was significantly greater (P < 0.001) than the leak for the upper limb (15 (5) %). Moreover, in each of 10 volunteers, the leak was always greater for the lower than the upper limb. During the first 3 min after tourniquet deflation the loss of radioactivity was 58 (8) % of the maximal amount for the upper limb and 39 (8) % for the lower limb (P < 0.004) than the leak for the upper limb (15 (5) %). We conclude that IVRA for the lower limb can be associated more frequently with a shorter duration of successful anaesthesia and/or failure. (Br. J. Anaesth. 1995; 75: 269–273)

Key words

Anaesthetic techniques, regional. Complications, tourniquet failure.

I.v. regional anaesthesia (IVRA), first described by Bier in 1908 [1] and re-introduced by Holmes in 1963 [2], is now a widely used technique for minor surgical procedures of the extremities. Although generally considered simple, safe and reliable, this technique can be associated, even in the presence of a correctly inflated tourniquet, with life-threatening complications [3–6], including death [7], attributed to the leak of local anaesthetic into the systemic circulation. The leak during IVRA has been documented using different methodologies, such as measurement of plasma concentrations of local anaesthetic in clinical studies [8–10] or injections of contrast medium [4, 6] and radiolabelled compounds [11] during simulated IVRA.

Although IVRA has been popular for upper limb surgery for many decades, in the past 10 yr the use of IVRA has been advocated for ankle and foot surgery [10, 12–15]. During IVRA for lower limb surgery, Davies and Walford [10] reported a detectable plasma concentration of local anaesthetic in all patients, despite a correctly inflated tourniquet placed above the ankle. As the same author had described in a previous study [9] a lower incidence of a leak during IVRA for hand surgery, it can be postulated that the leak under the calf tourniquet may be greater than that under the arm tourniquet. However, no quantitative evaluation and no comparison between upper and lower limb leaks during IVRA have yet been reported in the literature. Using a radiolabelled substance, the present study was designed to measure precisely and to compare the leak under the tourniquet during simulated IVRA of both upper and lower limbs in the same subject.

Subjects and methods

After institutional approval and informed written consent, we studied 10 healthy volunteers (five men). Morphological features such as height, weight and circumference of the limbs at tourniquet level were measured in each volunteer, in addition to the volume of the limb distal to the tourniquet using water displacement (Archimedes’ principle).

IVRA, which was simulated with radiolabelled N-(2,6-dimethylphenylcarbamoylmethyl) iminodiacetic acid (HIDA), was performed in two separate sessions, once on the upper limb and once on the lower limb in the same volunteer. Allocation of the limb for the sessions was random and the two sessions were separated by an interval of at least 1 week. HIDA, a compound currently used in biliary tract investigation, was chosen because it is chemically similar to lignocaine (fig. 1) and has a comparable tissue distribution [16–18].

For each session two 22-gauge venous catheters were inserted, either in a vein on the back of the hand and in the cephalic vein at the wrist, or in a vein on the dorsum of the foot and in the internal saphenous vein at the ankle level (fig. 2). The distal catheter was used for HIDA injection and the proximal to measure venous pressure. For upper limb IVRA, a single-cuffed tourniquet, 8 cm wide, was placed on the arm 4 cm above the elbow; for lower limb IVRA,
a tourniquet 10 cm wide was placed around the calf 4 cm below the head of the fibula. These two cuff sizes were chosen according to the difference in perimeter observed between the arm and leg [19, 20].

After exsanguination with an Esmarch bandage, the tourniquet was inflated in all cases to a pressure of 300 mm Hg. Then, HIDA 0.1 mg, labelled with 100 Ci of 99mTc and diluted in 40 ml of saline, was injected over 2 min through the distal venous catheter. Twenty minutes after the end of injection, the tourniquet was suddenly deflated.

Tourniquet leak was determined in the supine subject by measuring the radioactivity of the limb distal to the tourniquet with a gamma camera (Elscint Apex 415). One cumulative image was recorded every 30 s, starting at the end of injection of the radiolabelled HIDA and over the 20 min of tourniquet inflation after the end of injection and for 20 min after tourniquet deflation. Natural decay was controlled by parallel assessment of a control sample of 100 µCi of 99mTc; background radiation was also measured simultaneously. The precision of the technique is ±2%.

Individual image activities were corrected for background radioactivity and control sample decay. They were then normalized to a fraction of maximal radioactivity, where maximal radioactivity was taken as the maximum activity value after the end of injection of HIDA. The values obtained represent the amount of radioactivity remaining in the limb, expressed as percentages, every 30 s between the end of injection and the end of the procedure (40 min with 80 values).

We calculated the percentage of tourniquet leak according to the following formula:

\[
\text{percentage of tourniquet leak} = \left( \frac{\text{maximal radioactivity} - \text{minimal radioactivity}}{\text{maximal radioactivity}} \right) \times 100%
\]

where minimal radioactivity is the value measured 20 min after the end of injection of HIDA just before tourniquet deflation. In addition, for both limbs the loss of radioactivity during the first 3 min after tourniquet deflation and during the following 17 min was calculated, in addition to the remaining radioactivity at the end of the procedure (20 min after tourniquet deflation).

Venous pressure distal to the tourniquet was recorded continuously during injection and for the following 3 min after the end of injection, using a pressure transducer (Hewlett Packard) connected to the proximal venous catheter and a polygraph (Kontron W + W). The electrocardiogram was monitored continuously and non-invasive arterial pressure (Dinamap) was recorded at 5-min intervals.

Results are expressed as mean (SD). Upper and lower limb data were compared using a paired t test, and the relationship between the leak and other variables was calculated using regression analysis. \( P < 0.05 \) was considered statistically significant.

Results

The mean age of the volunteers was 35 (range 25–45) yr, mean height was 171 (sd 10, range 153–187) cm and mean weight 68 (16, 49–95) kg. The subjects’ morphological features, and maximal venous pressure and maximal mean arterial pressure during the procedures are presented in table 1 for both sessions. The only significant different between limbs was the greater circumference of the lower limb.

Table 1

<table>
<thead>
<tr>
<th>Volume (ml)</th>
<th>Circumference (cm)</th>
<th>Maximal VP (mm Hg)</th>
<th>Maximal MAP (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper</td>
<td>1737 (485)</td>
<td>26.5 (2.9)</td>
<td>50 (36)</td>
</tr>
<tr>
<td>limb</td>
<td>1050–2430</td>
<td>22–30.5</td>
<td>3–100</td>
</tr>
<tr>
<td>Lower</td>
<td>1980 (610)</td>
<td>34 (2.5)**</td>
<td>71 (60)</td>
</tr>
<tr>
<td>limb</td>
<td>1300–3200</td>
<td>30–38</td>
<td>33–225</td>
</tr>
</tbody>
</table>
Leak during IVRA

The gamma camera pictures shown in figure 3 illustrate the leak under the tourniquet observed in one subject. Individual values for upper and lower limb leaks during the 20 min of tourniquet inflation are shown in figure 4. In each of the 10 volunteers, the measured leak was greater for the lower than the upper limb. The difference in mean leak values between the upper and lower limbs over the 20 min of tourniquet inflation was significant ($P < 0.004$): 15.2 (4.9) % (range 9.1–24.7 %) for the upper limb vs 29.4 (8.0) % (19.6–44.3 %) for the lower limb.

After tourniquet deflation, the mean percentage loss of radioactivity during the first 3 min for the upper limb was 58.1 (8.4 %) (47.3–74.7 %) of the maximal values which was significantly greater ($P < 0.001$) than the 38.9 (7.7 %) (23.4–53.3 %) loss for the lower limb. During the following 17 min, the mean percentage loss of radioactivity was similar for both limbs: 11.0 (3.0) % (5.2–16.2 %) for the upper limb and 11.4 (2.5) % (7.9–15.1 %) for the lower limb. The remaining percentage values of maximal radioactivity still present 20 min after tourniquet release were 15.6 (4.5 %) (7.6–23.0 %) for the upper limb and 20.5 (2.6) % (16.5–25.0 %) for the lower limb ($P < 0.006$).

Venous pressures before exsanguination, before and during injection, and for the following 3 min are presented in figure 5. There was no significant difference between the upper and lower limbs for the control values before injection (before and after exsanguination) or for the 120 s of injection. A significant difference ($P < 0.05$) between upper and lower limb venous pressures was observed during the descending phase after the end of injection, the pressures in the lower limb remaining higher between 180 and 300 s.

There was no significant correlation between the amount of upper and lower limb leaks and the morphological features of the volunteers, maximal venous pressure during injection or maximal mean arterial pressure (table 2).

**Figure 5** Evolution of venous pressures (VP) for the upper (●) and lower (○) limbs during the 120 s of injection and during the 180 s after the end of injection (mean ± s). B = Before exsanguination, S = start of injection, End = end of injection. *$P < 0.05$.

**Table 2** Correlation coefficient between the leak of the upper and lower limbs and morphological features or maximal venous pressure (VP). $r > 0.576$ for significance $P < 0.05$

<table>
<thead>
<tr>
<th>Feature</th>
<th>Upper limb leak</th>
<th>Lower limb leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.070</td>
<td>0.160</td>
</tr>
<tr>
<td>Weight</td>
<td>0.266</td>
<td>0.190</td>
</tr>
<tr>
<td>Circumference</td>
<td>0.460</td>
<td>0.205</td>
</tr>
<tr>
<td>Volume</td>
<td>0.290</td>
<td>0.200</td>
</tr>
<tr>
<td>Maximal VP</td>
<td>0.566</td>
<td>0.042</td>
</tr>
</tbody>
</table>

**Discussion**

Leakage of local anaesthetics under a correctly inflated tourniquet during IVRA has been demonstrated by many authors using systemic venous measurements of local anaesthetic [8–10], radiographic contrast dye [4, 6] or labelled compounds [11]. However, the methods used in these studies did not allow quantification of tourniquet leak, mainly because of the confounding effects of volume of...
distribution, metabolism and excretion of local anaesthetic or other markers. To our knowledge, the present study is the first investigation designed specifically to quantify and compare the leak under the tourniquet during simulated IVRA of the upper and lower limbs. By using elimination curves of an injected radio labelled compound (99mTc-HIDA), our study demonstrated a two-fold greater leak for the lower (2%) than the upper (15%) limb over 20 min.

The use of 99mTc-HIDA, with a chemical structure similar to that of lignocaine, is well established in hepatobiliary imagery [16–18]. In the present study the changes in radioactivity remaining in the limb were measured rather than the leak in the systemic circulation, as in the study of Lillie, Glynn and Fenwick [21], where the same isotope (99mTc in saline) was assessed with a gamma camera in the contralateral hand. The method used in our study allows precise quantification of the leak and residual tissue binding after tourniquet release. In order to achieve maximal precision, radioactive control sample decay with time and background radiation noise were measured and compensated for by normalization of the data.

In the present study we used all of the measures recommended previously to avoid leak under the tourniquet. Exsanguination was performed with an Esmarch bandage, the solution was injected at the distal extremity of the limb, the rate of injection was 0.3 ml s$^{-1}$ and the inflation pressure of the tourniquet was 300 mm Hg [11]. In addition, the sizes of the tourniquets (8 cm and 10 cm) were wider than generally used for IVRA (6 cm).

The difference in leak between the upper and lower limbs cannot be attributed to the difference in circumference or volume of the limbs. The mean volumes of both limbs were comparable, and although the circumference of the lower limbs was significantly greater than that of the upper limbs, we feel that this difference of about 20% was compensated for by the difference in width of the tourniquets (8 cm for the upper limb vs 10 cm for the lower limb). Thus the effective tourniquet pressure, which represents the pressure transmitted to the underlying tissues, was probably similar for both limbs [19, 20]. Furthermore, despite the wide range in anthropometric features of the volunteers, there was no correlation between height, weight, volume or circumference of the limbs and the leak.

It has been suggested that possibly by exceeding the occluding pressure exerted by the tourniquet the increase in venous pressure during IVRA may be responsible for the leak [6, 11, 22, 23]. Grice and colleagues defined the concept of "maximum venous pressure" which reflects the pressure when leakage of solution under the tourniquet occurs. This pressure may be much lower than the measured tourniquet pressure, especially when a narrow tourniquet (5–6 cm) is used [11]. In the present study the highest venous pressure was observed at the end of injection, but it did not differ between the limbs. In addition, there was no correlation between maximal venous pressure and leak in both limbs. However, significantly higher values of venous pressure for the lower limb were noted from 60 to 180 s after the end of injection, suggesting lower compliance of the venous system of the leg in comparison with the arm. As the absolute values of venous pressure were much lower than the effective pressure of the tourniquet, we do not feel that the leak under the tourniquet or the difference in leak between the upper and lower limbs can be attributed to the variation in venous pressures.

As suggested by Davies and Walford [10], the possible cause of the greater leakage in the lower limb could be the presence of two bones, protecting the interosseous tissues from the effect of the tourniquet. Intraosseous leak has been suggested [24]: the amount would also be greater in the presence of two bones. However, no direct illustration of the exact location of passage of radio labelled substance under the tourniquet could be obtained using our method.

Immediately after tourniquet release, there was a rapid decrease in radioactivity in both limbs in the first 3 min, that is 58% (from 85% to 27%) of the maximal value for the upper limb and 39% (from 71% to 32%) for the lower limb ($P < 0.001$). These findings indicate that 20 min after injection, about 50% of the radio labelled substance was washed out rapidly, and suggest that an important part of HIDA remains in the intravascular compartment rather than fixed to the tissue. We can postulate that local anaesthetics, which are chemically similar to HIDA, would behave in a similar manner. The significantly larger decrease in radioactivity in the upper limb could be explained by higher remaining radioactivity before tourniquet deflation compared with the lower limb, and possibly by higher venous capacitance, higher regional blood flow, or both. Thus systemic toxic reactions during IVRA for arm surgery could theoretically be expected more frequently, after tourniquet deflation.

The rapid decrease in radioactivity after tourniquet release was followed by a much slower decay (11% over 17 min) of the maximal value for both the arm and leg, suggesting prolonged extravasation of the substance. Twenty minutes after tourniquet deflation the remaining radioactivity was 16% for the upper limb and 21% for the lower limb ($P < 0.006$). This difference is not clinically relevant and cannot be explained by morphological features as the volumes of the upper and lower limbs were comparable. No clinical study has investigated the amount of substance injected which remains bound to the tissue after tourniquet release. However, our findings are supported by qualitative studies reported previously. Indeed, by comparing plasma prilocaine concentration curves after direct i.v. injection and after IVRA, Hargrove and colleagues [25] demonstrated that the total dose of local anaesthetic was not released rapidly into the systemic circulation after tourniquet deflation. In a study using bupivacaine for IVRA, Magora and co-workers [26] noted clinical and electrophysiological effects consistent with binding of local anaesthetic to the nerves of the upper limb for up to 20 h after cuff release. In an experimental study in dogs, Cotev and Robin [27] determined $^{14}$C-lignocaine binding during and after IVRA using biopsies of different
tissues, and demonstrated significant residual binding 15–30 min after tourniquet release, the amount being consistent with our results.

In conclusion, we were able to demonstrate that IVRA, performed according to currently accepted safety criteria, was associated with significant leaks under the tourniquet. The leak while the tourniquet was inflated was twice as great for the lower limb as for the upper limb, suggesting that during IVRA for the lower limb a greater incidence of failure and also a shorter duration of anaesthesia could be expected. On the other hand, there was rapid washout of substance for both limbs when the tourniquet was deflated, but at a significantly higher rate for the upper limb, emphasizing that at this time close supervision is mandatory to detect and treat potentially toxic reactions.

References

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