Anaesthesia, 2000, **55**, pages 21–26

Tourniquet pain in a volunteer study: effect of changes in cuff width and pressure

J.-P. Estebe, A. Le Naoures, L. Chemaly and C. Ecoffey

Service d'Anesthèsie Rèanimation 2, Centre Hospitalier Règional et Universitaire de Rennes, Hôtel Dieu, 2 Rue de l'Hôtel Dieu, 35064 Rennes Cedex, France

Summary

This study examines the relationship between pneumatic tourniquet cuff size, occlusion pressure and the resulting pain. Two tourniquet cuff widths were used, a wide (14 cm) and a narrow cuff (7 cm). Twenty volunteers were divided into two groups for tourniquet application: a pressure group in which the tourniquet was inflated to a pressure equal to the systolic pressure + 100 mmHg, and a saturation group in which the tourniquet was inflated to 10 mmHg above the loss of arterial pulse, as indicated by cessation of pulse waveform on an oximeter. According to a randomised cross-over protocol, subjects were studied using wide and narrow cuffs simultaneously and/or successively on both arms. Pain was assessed by subjects by means of a visual analogue score (0–10 cm). Occlusion pressures were similar for all volunteers in the pressure group and significantly higher than those in the saturation group with both the wide and narrow tourniquets. The wide cuff data turned out to be significantly lower than the narrow cuff results. Subjects in the pressure group could tolerate pain with the narrow cuff for significantly longer than with the wide cuff. However, in the saturation group, volunteers tolerated the wide cuff for longer. Pain intensity increased more rapidly in those in the pressure group with the wide cuff than with the narrow cuff. In contrast, volunteers in the saturation group found the narrow cuff to be more painful than the wide cuff. In conclusion, this study has shown that a wide tourniquet cuff is less painful than a narrow cuff if inflated at lower pressures and at these lower pressures it is still effective at occluding blood flow.

Keywords *Equipment*; tourniquets; *Pain*; measurement.

Correspondence to: Dr J.-P. Estebe
Accepted: 16 June 1999

Pneumatic tourniquets are often used to provide a bloodless operating field and to perform intravenous regional anaesthesia but they carry a risk of complications. Indeed, skin, muscles, nerves and vessels can be damaged by the mechanical pressure of the tourniquet, as a result of sagittal forces causing compression and axial forces causing stretching [1, 2]. Therefore, the extremities of a limb are affected by ischaemia. On the one hand, it has been suggested that the wider the tourniquet cuff, the lower the occlusion pressure [3, 4]. On the other hand, it has also been suggested that a wider tourniquet cuff results in more pain [5]. However, this study was carried out at pressures that are commonly used for narrow tourniquets. The aim of the study was to compare tourniquet pain tolerance by using two different tourniquet widths at two different levels of pressure: at 100 mmHg above systolic blood pressure and at the lowest effective occlusive pressure.

Methods

The study was approved by our local medical ethics committee. The volunteers, who were staff members of the emergency and orthopaedic units, gave written, informed consent. Individuals in excess of 125% of their ideal body weight or who had hypertension, skin problems, neuralgia or were receiving medication were not studied. Twenty healthy and unpremedicated volunteers remained (aged 29–45 years, 10 of whom were women) to undergo the three experiments.

Subjects were in a relaxed, reclining position and were unable to see any clocks or monitoring equipment. Systemic arterial pressure was measured noninvasively every 5 min on their legs. ECG electrodes were placed and connected to a combined ECG and arterial pressure monitor and digital plethysmograph. Pneumatic tourniquets were applied on the

mid-upper arm over a single wrap of cotton wool padding. Pulse oximetry (S_pO_2) was applied to the middle finger of the experimental arm throughout the study so as to confirm the absence of the arterial pulse. After a 10-min stabilisation period, the arm was exsanguinated by elevation to 90° for 5 min. After this, the tourniquet cuff was inflated and the arm was extended and placed in a resting position.

Cuffs of two different widths were used. The wide one was a 14-cm single-bladder Zimmer low pressure, contour arm cuff for orthopaedic surgery; the narrow one was a 7-cm proximal double-bladder Zimmer contour arm cuff for intravenous regional anaesthesia. In order to study the effect of two different sized cuffs with two different tourniquet pressure levels, the volunteers were divided into two groups of 10. The 'pressure' group ($n = 10$) was studied in an emergency operating room. In this group the tourniquet was inflated to the systolic pressure + 100 mmHg based on blood pressure in the respective arm. The 'saturation' group ($n = 10$) was studied in the orthopaedic recovery room. In this group the tourniquet was inflated until the arterial pulsation had disappeared + 10 mmHg (the pulses being measured on the digital plethysmograph oscilloscope applied to the middle finger). Precise pressure control was sustained with a microprocessor controller (ATS 1500 Zimmer tourniquet regulator, Ohio USA). Whenever the S_pO_2 trace appeared, the pressure was increased by 15 mmHg.

The experimental protocol consisted of three distinct test phases. Each group was tested in accordance with a randomised cross-over protocol. The two different sized tourniquets, known as wide and narrow, were placed on both arms at the same time. Two days later, wide or narrow cuffs were placed in succession onto each arm and after a 2–3 h rest period, a cross-over test on the opposite arm was undertaken (2,1,1 protocol). In order to avoid a design flaw effect, five of the 10 subjects in each group underwent the experiment the opposite way, i.e. the tourniquet was first placed in succession on each arm then sited simultaneously 2 days later (1,1,2 protocol).

Tourniquet pain was assessed according to a 0–10-cm visual analogue scale (VAS), whereby '0' represents no pain or discomfort and '10' represents the worst pain and/or discomfort that the subject can possibly imagine. VAS evaluations were conducted by the same observer, just before and after inflating the tourniquet; at 1 min and thereafter every 2.5 min. After deflation, measurements continued until the VAS had decreased to < 1 cm. Every volunteer was asked to assess his/her pain according to the VAS and to give a precise description of it. During the first experiment, pneumatic tourniquets were deflated either at the subject's request, when his or her pain tolerance limit was reached, or when the VAS was > 6 cm. Then, for each test, volunteers were asked to tolerate the pain for as long as possible, but also to try to recall the degree of pain so that

Table 1 The mean occlusion pressure of the narrow and wide cuffs in the 'pressure' and 'saturation' groups

	Narrow cuff	Wide cuff	
Pressure group; mmHg	258 (12)	260 (8)	NS
Saturation group; mmHg	202 (4)	147 (4)	$p < 0.0001$
	$p < 0.0001$	$p < 0.0001$	

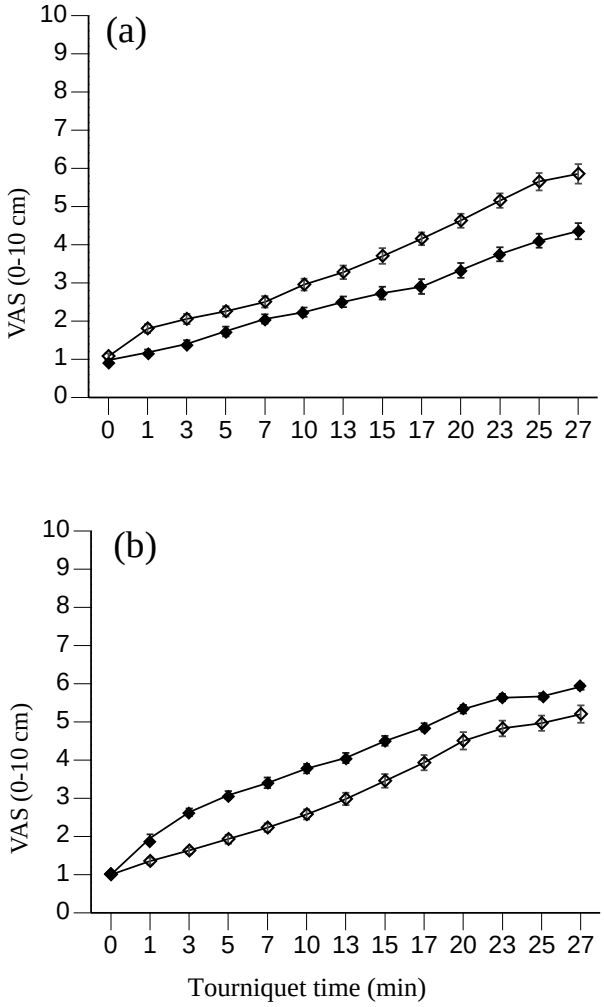

Figure 1 (a) For the pressure group ($n = 10$), mean (SEM) linear VAS evolution in response to the maintenance of tourniquet inflation is shown with open diamonds for wide (14-cm) tourniquet cuffs and closed diamonds for narrow (7-cm) tourniquet cuffs. *$p < 0.05$. (b) For the saturation group ($n = 10$), mean (SEM) linear VAS evolution in response to the maintenance of tourniquet inflation is shown with open diamonds for wide (14-cm) tourniquet cuffs and closed diamonds for narrow (7-cm) tourniquet cuffs. *$p < 0.05$.

their reaction could be compared for further experiments. The assessment of voluntary movement and touch sensitivity (tactile pressure) of the hand were evaluated regularly, with the requirement that subjects should keep their eyes closed.

For each subject, data were analysed using a parametric one-way analysis of covariance and paired Student's *t*-test. For each group and intergroup comparison, the data were analysed using parametric unpaired *t*-tests. All results are expressed as mean (SEM) and analysed using ANOVA with repeated measures. A value of $p < 0.05$ was considered to be statistically significant.

Results

No subject was excluded from our study. The demographic characteristics (age, sex ratio, height, weight and right-handed ratio) were similar between the groups. All subjects experienced tourniquet pain in every tourniquet test (100%).

The occlusion pressures used are shown in Table 1. The occlusion pressures for both the wide and narrow tourniquets in the pressure group were significantly higher than those in the saturation group. For the saturation group, the occlusion pressures inherent to the wide tourniquet were significantly lower than those yielded by the narrow tourniquet. When using the same tourniquet cuff width for one and the same subject in all groups, we found that there was no difference in occlusion pressure between the first and the second experiments. There was no difference between the dominant or nondominant arm. It was never necessary to increase the pressure level of the tourniquet because of pressure failure with the appearance of arterial pulse waveform.

Figure 1a shows the mean VAS scores for the pressure group for the wide and narrow cuffs (according to the

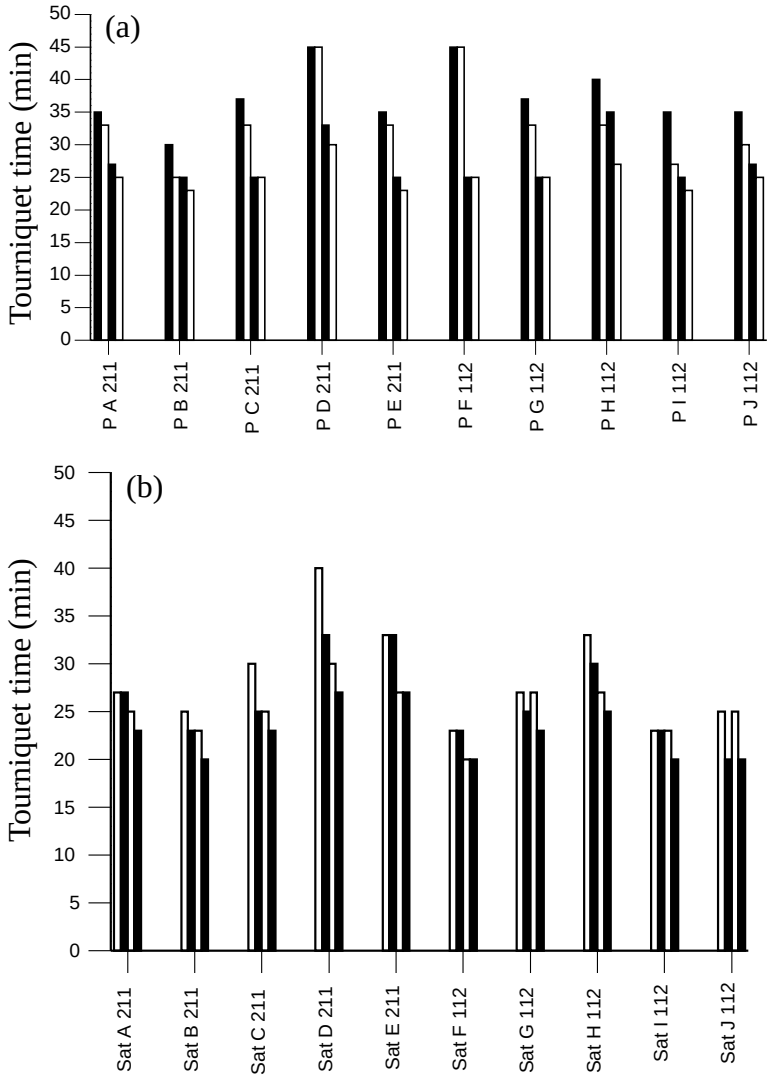

Figure 2 (a) In the pressure group, for each volunteer (A–J; $n = 10$), the pneumatic tourniquet tolerance time to pain is shown by bar graphs: clear for wide (14-cm) tourniquet cuffs, and black for narrow (7-cm) tourniquet cuffs. In the first five subjects (A–E) the two types of tourniquet (wide and narrow) were applied simultaneously on both arms and 2 days later, wide and/or narrow tourniquets were applied successively after a 2–3 h rest period with a cross-over trial on the opposite arm (2,1,1 protocol). In the five remaining subjects (F–J), tourniquets were first applied successively and then simultaneously 2 days later according to the same cross-over protocol (1,1,2 protocol). (b) In the saturation group, for each volunteer (A–J; $n = 10$), the pneumatic tourniquet tolerance time for pain is shown by bar graphs: clear for wide (14-cm) tourniquet cuffs and black for narrow (7-cm) tourniquet cuffs. In the first five subjects (A–E), the two types of tourniquet (wide and narrow) were applied simultaneously on both arms and 2 days later, the wide and/or narrow tourniquet were applied successively after a 2–3 h rest period with a cross-over trial on the opposite arm (2,1,1 protocol). In the five remaining subjects (F–J), tourniquets were first applied successively, then simultaneously 2 days later according to the same cross-over protocol (1,1,2 protocol).

protocol 2,1,1 and 1,1,2). Figure 1b shows the saturation group results. In the pressure group, the mean VAS scores with the wide cuff were significantly higher and increased faster than the VAS scores with the narrow cuff. In contrast, in the saturation group, the mean narrow cuff VAS scores increased significantly higher and faster than the wide cuff scores. These results were confirmed with the analysis of each subject's data. Individual results of tourniquet pain tolerance time are shown in Fig. 2a for the pressure group, and in Fig. 2b for the saturation group. With regard to pain tolerance, the pressure group subjects were able to tolerate the narrow cuff for significantly longer than the wide cuff [36 (6) min, 26 (3) min, $p < 0.001$, respectively]. But conversely, the saturation group volunteers tolerated the wide cuff better [28 (5) min for wide, 24 (9) min for narrow, $p < 0.01$].

Just after the tourniquet was inflated, the first sensation felt was a pressure pain at the site of the tourniquet cuff (first component of pain). Rapidly, within 3 (2) min, a tingling sensation developed, mainly in the hand. This tingling sensation increased progressively and after 10–15 min [12 (1) min] the arm began to ache more than the original pain and became even worse (second component of pain). Hypoaesthesia occurred about 10 min after the tourniquet has been inflated [10 (1) min] causing numbness mainly in the hand. After about 20 min, the fingers became completely anaesthetised [22 (7) min], and, 5 min later, the muscles were completely paralysed up to the wrist [27 (3) min; third component of pain]. The sensations experienced were not significantly different between the narrow and wide cuffs, in both the pressure and the saturation groups. However, when both cuffs were applied simultaneously, the tingling sensations and numbness seemed to appear slightly earlier with the narrow cuff than the wide tourniquet. Conversely, paralysis seemed to decrease earlier with the wide cuff. At first, tourniquet deflation seemed to relieve the subject's pain within a few seconds and to produce a sensation of well-being. But within less than 1 min, all of the subjects described a warming sensation which quickly turned into an aching sensation of burning. Limb reperfusion was accompanied by other pain, such as a tickling feeling, which soon became a throbbing sensation that grew even more painful when touched and was accompanied by muscle cramps. Pain reached a peak, mean VAS = 7 (4) cm, after 2 min, but it was not significantly greater than the pain experienced before tourniquet deflation occurred. Both groups reacted the same way and the pain subsided within 6–7 min.

Similarly for each group, there was a slight, insignificant increase in systolic and diastolic blood pressures above the pre-inflation level [140 (17) mmHg, 70 (7) mmHg for systolic and diastolic blood pressure, respectively] before deflation [150 (17)mmHg, 79 (8) mmHg]. Blood pressure returned to a baseline level 1 min after tourniquet deflation had occurred. The heart rates for all tests were not significantly different from test values at the time of both initial inflation and deflation.

Discussion

The main results of this investigation showed that for each subject the pain developed earlier and faster using the wide pneumatic tourniquet at high pressures (100 mmHg above systolic blood pressure). But, conversely, for all of the subjects, the wide cuff inflated at a lower occlusive pressure (up to arterial pulse loss + 10 mmHg) was less painful. The occlusive pressure that was monitored on the oscilloscope of the digital plethysmograph is lower than the pressure with which we traditionally work, but it still permits valid comparison. The pressure levels and tourniquet widths had no effect on reperfusion pain. In contrast, during the tests on the saturation group it appeared that the wide cuffs were much more effective than the narrow cuffs with respect to occlusion pressure. Not only were they less painful at a lower pressure, but they also allowed occlusion to take place at lower pressures. This is of clinical importance and is especially relevant to intravenous regional anaesthesia.

As far as the evolution of the VAS scores was concerned, each volunteer in all groups showed similar graph readings on the first and second tests, in the case of both cuffs (except for the saturation group at 20 min after inflation, $p < 0.05$). But the second test graph always proved to be higher than the first. The second tourniquet pain tolerance time with the same cuff was similar (27.5%) or shorter (73.5%) than during the first experiment, but never longer, the mean difference was 3 (1) min (see Fig 2a, b). It was not the result of a design flaw but probably to a noteworthy experiment on the volunteer tolerance of subjects. This probably had an effect on the results, which remained clearly significant. With regard to the differences in tourniquet pain tolerance time between the pressure group and the saturation group, the reason remains unclear: it could be due to the fact that the examiner who performed the experiments was known in the first unit but not in the second one.

Pain from tourniquet use was first studied in 1952 [6]; a number of mechanisms has been invoked to explain its cause [4, 7]. The same sequence of pain during tourniquet inflation and deflation has been described previously in studies conducted on volunteers [5, 8]. However, the results of our study differ notably from the results of these studies. Following the application of the wide (7-cm) or narrow (5-cm) pneumatic tourniquet on the lower extremity, Hagenouw *et al.* showed that significantly greater pain occurred when using a higher pressure (300 vs. 400 mmHg) only in the period immediately after cuff

inflation, but they did not demonstrate differences in tolerance time, mean tourniquet inflation time = 31 (10) min [5]. They also showed that the narrower tourniquet needed a higher occlusive pressure than did the wider one. On the upper extremity, Crews *et al.* demonstrated no difference in tolerance times, mean tourniquet inflation time = 34 (13) min, or in pain intensity related to the cuff width (5 and 10 cm of width cuff), or with respect to inflation pressure (200 and 300 mmHg pressure) [8]. In these two volunteer studies, subjects did not test the two different sized cuffs simultaneously. However, a 5-day rest period was much too long for the subjects to remember the pain they had experienced precisely enough so it could be assessed accurately. In our study, the volunteers were able to compare pain in both arms at a given time or within a 2-h period. In addition, these two studies did not compare pressures currently used in orthopaedics, which range from 100 to 150 mmHg above the systolic blood pressure, with the lowest appropriate occlusive pressure, as we did. Experiments carried out in parallel and after a short rest period of 2 days could explain the slightly lower tourniquet duration of this study because of the protocol, which stopped at 6–7 cm VAS score, not necessarily at the worst pain. Our results with respect to pain, sensitivity and motor blockade were similar to those of previous studies. Another volunteer study confirmed that the function of A-β fibres (touch), C fibres (skin conductance level) and the motor function was progressively suppressed during tourniquet inflation. Also, recovery occurred within a few minutes after deflation [9].

The aetiology and neural pathways involved in tourniquet pain remain controversial, but are probably multifactorial [4]. The pain sensations described could be of neurogenic origin. The classical neurogenic hypothesis was probably the most predominant one [7]. Nerve compression was classically thought to be mediated by unmyelinated, slow-conducting C fibres normally inhibited by earlier arriving fast impulses conducted by myelinated A-δ fibres [10, 11]. Mechanical compression would block the large A-δ fibres, leaving uninhibited C fibres still functioning. It has been demonstrated on animal models that neurophysiological (a compound of motor action potential amplitudes and nerve conduction velocity), as well as neuropathological fibre damage was correlated with tourniquet pressure [12]. Unfortunately, serious complications, such as permanent nerve palsies may occur, especially with a straight tourniquet or with high occlusive pressures [3, 4], but of course this damage is also partly as a result of a long ischaemic period. The response of spinal dorsal horn neurones to mechanical compression could be indicative of dynamic receptive field plasticity [13]. A study of animals has shown evidence of expansion of the receptive field of nociresponse neurones in response to tourniquet pain [14, 15]. The expansion of the receptive fields of primary proximal nociceptors inherent to the tourniquet may explain the relative resistance of this pain to an otherwise adequate level of anaesthesia. Skin could contribute significantly to the superficial component of tourniquet pain [16, 17]. Muscle pain could also play a part in tourniquet pain during inflation and after tourniquet release [18], metabolic changes have, however, shown significant correlation with tourniquet time, but not with tourniquet pressure [19]. If the tourniquet pain has three components: local pain from the compression by the inflated cuff, neuropathic pain induced by nerve compression and ischaemic pain in the arm, the size of the cuff and the pressure are two dominant and different causes of pain during tourniquet inflation and probably following tourniquet deflation [20].

In conclusion, this study has shown that a wide cuff is much more effective in the occlusion stage than a small cuff and is less painful when pressure is limited to arterial pulse loss. Conversely, a wide cuff ('new device') proves to be more painful if pressure ('standard pressure') is adjusted to 100 mmHg above systolic blood pressure.

References

1 McLaren AC, Rorabeck CH. The pressure distribution under tourniquets. *Journal of Bone and Joint Surgery* 1985; **67A**: 433–8.

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

3 Pedowitz RA, Gershuni DH, Botte MJ, Kuiper S, Rydevik BL, Hargens AR. The use of lower tourniquet inflation pressures in extremity surgery facilitated curved and wide tourniquets and an integrated cuff inflation system. *Clinical Orthopaedics and Related Research* 1993; **287**: 237–44.

4 Estebe J-P, Malledant Y. Le garrot pneumatique d'orthopèdie. *Annales Françáises d'Anesthèsie et de Rèanimation* 1996; **15**: 162–80.

5 Hagenouw RRPM, Bridenbaugh PO, Van Egmond J, Stuebing R. Tourniquet pain: a volunteer study. *Anesthesia and Analgesia* 1986; **65**: 1175–80.

6 Cole F. Tourniquet pain. *Anesthesia and Analgesia* 1952; **31**: 63–4.

7 Estebe J-P, Kerebel C, Brice C, Le Naoures A. Douleur et garrot pneumatique d'orthopèdie. *Cahiers d'Anesthesiologie* 1995; **43**: 573–8.

8 Crew JC, Hilgenhurst G, Leavitt B, Denson DD, Bridenbaugh PO, Stuebing RC. Tourniquet pain: the response to the maintenance of tourniquet inflation on the upper extremity of volunteers. *Regional Anesthesia* 1991; **16**: 314–17.

9 Ramamurthy S, Hoffman J, Rogers JN, Hatch JP. Effect of tourniquet on nerve function and blood flow. *Anesthesiology* 1994; **81**: A1024.

10 Gielen MJM, Stientra R. Tourniquet hypertension and its prevention: a review. *Regional Anesthesia* 1991; **16**: 191–4.
11 Hodgson AJ. A proposed etiology for tourniquet-induced neuropathies. *Journal of Biomedical Engineering* 1994; **116**: 224–7.
12 Pedowitz RA. Tourniquet-induced neuromuscular injury: a recent review of rabbit and clinical experiments. *Acta Orthopaedica Scandinavica* 1991; **245**: 1–33.
13 Gelgor L, Mitchell D. Modality-specific hypersensitivity of dorsal horn convergent neurones during reperfusion of their receptive fields on the rat's tail. *Pain* 1993; **55**: 305–12.
14 Crews JC, Cahall MA. An investigation of the neurophysiologic mechanisms of tourniquet-related pain: changes in spontaneous activity and receptive field size in spinal dorsal horn neurons. *Regional Anesthesia and Pain Medicine* 1999; **24**: 102–9.
15 Bennet GJ, Xie YK. A peripheral mononeuropathy in rat that produces disorders of pain sensation like those seen in man. *Pain* 1988; **33**: 87–107.
16 Lowrie A, Jones MJ, Eastley RJ. Effect of a eutectic mixture of local anaesthetic agents (EMLA) on tourniquet pain in volunteers. *British Journal of Anaesthesia* 1989; **63**: 751–3.
17 Tsai YC, Lai YY, Chang CL. Comparison of the effect of EMLA cream, subcutaneous ring anaesthesia and a double cuff technique in the prevention of tourniquet pain. *British Journal of Anaesthesia* 1993; **70**: 394–6.
18 Mense S. Nociception from skeletal muscle in relation to clinical muscle pain. *Pain* 1993; **54**: 241–89.
19 Kokki HV, Väätäinen U, Penttilä I. Metabolic effects of a low-pressure tourniquet system compared with a high-pressure tourniquet system in arthroscopic anterior crucial ligament reconstruction. *Acta Anaesthesiologica Scandinavica* 1998; **42**: 418–24.
20 Ömeroglu AU, Uaner A, Tabak AYG, Güney Ö, Biimoglu AG, Günel U. The effect of using a tourniquet on the intensity of postoperative pain in forearm fractures. *International Orthopedics (SICOT)* 1998; **22**: 369–73.