The Use of Lower Tourniquet Inflation Pressures in Extremity Surgery Facilitated by Curved and Wide Tourniquets and an Integrated Cuff Inflation System

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Use of the lowest possible cuff inflation pressure should minimize the pathogenic effects of compression beneath the pneumatic tourniquet. Curved tourniquets (designed to fit conically shaped limbs) and wider tourniquets were associated with significantly lower arterial occlusion pressure (AOP) than standard, straight tourniquets on the arms and legs of 26 normal volunteers. These tourniquets were used with an integrated tourniquet inflation system in 29 upper-extremity and 31 lower-extremity surgeries. Mean tourniquet inflation pressures of 183.7 mm Hg and 208 mm Hg were used during various surgical procedures of the arm and leg, respectively. Incomplete hemostasis was associated with elevated systolic blood pressure in several cases, but acceptable surgical hemostasis was achieved by incremental increase of the cuff inflation pressure. Curved cuffs, wide cuffs, and an integrated cuff inflation system should facilitate the use of lower tourniquet inflation pressures in extremity surgery.

Pneumatic tourniquets are used commonly to produce a bloodless field in extremity surgery. Nerve and muscle injury tend to be greater beneath the tourniquet than distal to it, because of the combined effects of compression and local ischemia.[19] Use of the lowest possible tourniquet inflation pressure should minimize injury caused by direct mechanical deformation of musculoskeletal soft tissues.

Tourniquet design affects the minimum cuff pressure needed to occlude pulsatile arterial flow. Standard, straight (*i.e.*, rectangular) tourniquets are designed to fit optimally on cylindrically shaped limbs. Human limbs may be conical in shape, however, particularly in extremely muscular or obese individuals.[22] Recently, curved tourniquets specifically designed to fit conical limbs have been introduced for clinical use. On the conically shaped rabbit thigh, a curved tourniquet occludes pulsatile arterial flow with lower inflation pressures than a straight cuff of equal width.[20] Wide tourniquets occlude blood

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flow at lower pressures than narrow tourniquets on upper and lower extremities.[2,16,17]

The purposes of the current study were to assess the minimum cuff pressure needed to occlude arterial blood flow using curved and straight tourniquets on healthy volunteers and to develop techniques to facilitate lower cuff inflation pressures in extremity surgery.

MATERIALS AND METHODS

The study included 26 normal volunteers (16 female, ten male), with a mean age of 28.4 years of age (range, 15–43), and 60 patients (57 men, three women), mean age 48 years (range, 23–79). Study protocols were approved by the Human Subjects Committee of the authors' institutions. Subjects gave informed consent before the study.

All subjects were positioned supine. Systolic blood pressure was either determined by auscultatory technique using a standard blood pressure cuff on the right upper arm, or this information was provided by an anesthesiologist. Limb circumference was measured at the longitudinal midposition of the various tourniquet cuffs. In the volunteer studies, the tourniquet was wrapped directly around the limb. In some patients, soft cotton roll was applied beneath the tourniquet, according to the surgeon's preference.

NORMAL VOLUNTEERS

Part 1: Comparison of 8-cm–Wide Curved and 8-cm–Wide Straight Tourniquets on the Lower Extremity. In random order, a standard, straight operating room tourniquet (8 cm wide) or a curved tourniquet (8 cm wide; radius of curvature, 132 cm) was applied to the right thigh of 14 normal volunteers. The tourniquet was connected to a Kidde tourniquet inflator (W. Kidde, Bloomfield, New Jersey), which was connected in parallel to a calibrated pressure transducer (HP 1280, Hewlett Packard, San Diego, California) and chart recorder (HP 7754A). A Doppler flow meter (Model 806-A, Parks Electronics, Beaverton, Oregon) was positioned over the posterior tibial artery, and auditory output was monitored by a single observer. A pulse oximeter (Biox 3700, Ohmeda, Boulder, Colorado) was placed on the pad of the middle digit of the foot, and output was recorded using the chart recorder. The tourniquet was slowly inflated to the arterial occlusion pressure (AOP), which was defined as the minimum cuff pressure needed to occlude distal pulsatile arterial flow. The Doppler AOP (D-AOP) was defined as the lowest cuff pressure to eliminate audible pulsations. The oximeter AOP (O-AOP) was determined directly from simultaneous chart recording of cuff inflation pressure and oximeter output. The mean of three sequential determinations was defined as the AOP for each cuff.

Part 2: Comparison of 8-cm–Wide Curved and Straight Tourniquets on Upper Extremities, and of 8-cm–Wide and 12-cm–Wide Curved Tourniquets on Lower Extremities. In random order, 8-cm-wide straight and 8-cm–wide curved cuffs were applied to the left upper arm, and 8-cm–wide curved and 12-cm–wide curved cuffs (radius of curvature, 132 cm) were applied to the left thighs of 12 subjects. The tourniquets were connected to a calibrated tourniquet inflator with a digital pressure display (ATS 1000, Zimmer Aspen Labs, Aspen, Colorado). A photoplethysmograph (PPG) sensor (PPG-13, Vasculab, Mountain View, California) was applied to the middle digital pad, and PPG output was displayed on an oscilloscope (HP 7803, Hewlett Packard). The PPG has been used extensively in the authors' vascular laboratory, and facilitates simple and accurate determination of limb blood pressure. The tourniquet was inflated beyond the AOP, and the pressure was slowly decreased until pulsatile flow resumed (similar to the standard technique for determination of systolic blood pressure). The cuff pressure at which pulsatile flow first resumed was defined as the AOP. The mean of three sequential determinations was defined as the AOP for each cuff.

PATIENT STUDY

Sixty patients who were scheduled to be treated with extremity surgery volunteered for the study. In the upper-extremity cases, patients were randomly assigned to either an 8-cm-wide straight cuff or an 8-cm–wide curved cuff. In the lower-extremity cases, patients were randomly assigned to either an 8-cm-wide straight cuff, an 8-cm–wide curved cuff, or a 12-cm–wide curved cuff.

The digital tourniquet inflator, PPG sensor, and oscilloscope, and the technique for determination of the AOP were identical to those described above in normal volunteers. After determination of the AOP, the tourniquet was deflated and the PPG sensor was removed. Limb exsanguination before cuff inflation was performed according to the preference of the operating surgeon. The tourniquet inflation pressure was set at the AOP plus 50 mm Hg for upper- and lower-extremity cases. If the surgeon reported inadequate hemostasis during the operation, the tourniquet pressure was increased in increments of 25 mm Hg until hemostasis was achieved. In these instances, changes in the systemic blood pressure from the initial time of

AOP determination were recorded by the anesthesiologist. At the conclusion of the surgery, the type of procedure, method of anesthesia, duration of tourniquet hemostasis, AOP, and maximum tourniquet pressure were recorded. In addition, surgeons were asked to rate subjectively the quality of surgical hemostasis (excellent, good, fair, or poor).

Statistical evaluation consisted of paired *t*-tests and linear regression analysis. Statistical significance was attributed to a *p* value less than 0.05. All data are presented as the mean ± standard deviation (SD).

RESULTS

Normal Volunteers

Part 1. The 8-cm–wide curved tourniquet occluded blood flow with significantly lower cuff inflation pressure than the straight cuff of equal width on the thighs of volunteers. The difference measured was 25.4 ± 16.1 mm Hg and 21.8 ± 17.1 mm Hg using the Doppler and oximeter techniques, respectively (paired *t*-tests, $p < 0.001$ both comparisons, Fig. 1). Overall, the mean AOP difference between the two measuring techniques was 5.9 mm Hg, with significant positive correlation between D-AOP and O-AOP. There was significant positive correlation between AOP and thigh circumference (TC) for both the curved tourniquet (D-AOP = 6.22 [TC] − 77.2; $r = 0.752$; $p = 0.002$) and the straight tourniquet (D-AOP = 6.14 [TC] − 44.0; $r = 0.782$; $p = 0.001$, Fig. 2). The mean systolic blood pressure in these volunteers was 125.5 mm Hg (range, 108–158 mm Hg), and the mean thigh circumference was 50.3 cm (range, 44–61 cm).

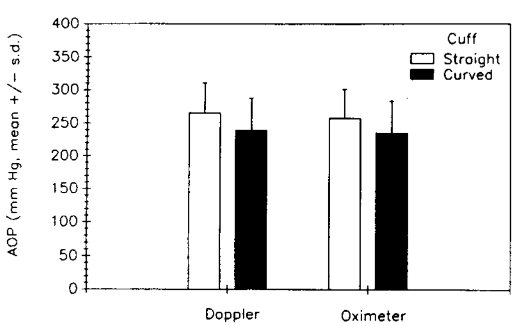

FIG. 1. AOP in the lower extremities of 14 volunteers measured with the Doppler and oximeter techniques. The 8-cm-wide, curved tourniquet occluded blood flow at significantly lower inflation pressure than the straight cuff of equal width.

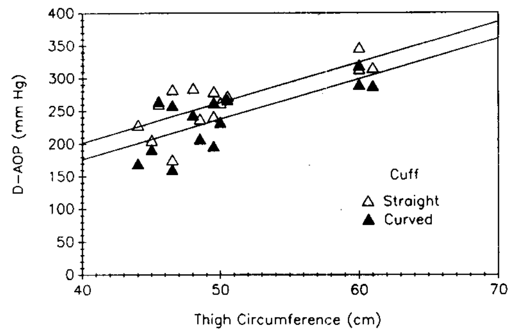

FIG. 2. Significant positive correlation of arterial occlusion pressure (D-AOP) and thigh circumference using the 8-cm-wide curved and 8-cm-wide straight tourniquets. The linear regression lines are shown (equations and correlation coefficients are in the text).

Part 2. In the upper extremities, AOP was significantly lower with the 8-cm–wide curved tourniquet (124.2 ± 10.5 mm Hg) than with the 8-cm–wide straight tourniquet (128.5 ± 13.9 mm Hg, paired *t*-test, $p = 0.026$). In the lower extremities, AOP with the 12-cm–wide curved cuff (154.4 ± 18.9 mm Hg) was significantly lower than AOP with the 8-cm–wide curved cuff (163.0 ± 23.2 mm Hg, paired *t*-test, $p = 0.014$, Fig. 3). The mean systolic blood pressure in these volunteers was 125.6 mm Hg (range, 100–154 mm Hg), the mean upper-extremity circumference was 27.8 cm (range, 23–33 cm), and the mean lower-extremity circumference was 52.7 cm (range, 45–59 cm).

Patient Study

Data for the upper- and lower-extremity procedures are presented in Tables 1 and 2, respectively. The mean tourniquet pressure used to induce surgical hemostasis in upper extremities was 183.7 mm Hg (range, 145–270 mm Hg). For lower-extremity surgeries, the mean tourniquet pressure was 208.0 mm

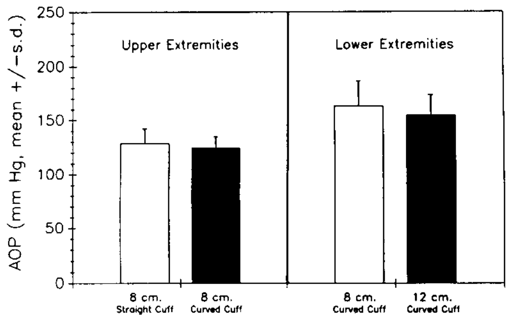

FIG. 3. AOP in 12 volunteers using the PPG technique. In the upper extremities, there was a small but statistically significant difference between the 8-cm-wide curved cuff and the 8-cm-wide straight cuff. In the lower extremities, the wider curved cuff occluded blood flow at significantly lower inflation pressures than the narrower curved cuff.

Hg (range, 160–280 mm Hg). Hemostasis was rated fair or poor in ten cases. Five of these cases were associated with an increased systolic blood pressure after AOP determination.

DISCUSSION

Catastrophic complications, such as permanent neurologic injury, are rare with present-day use of pneumatic tourniquets.[1,15,22] Some nerve palsies may be secondary to faulty pressure gauges causing excessive tourniquet inflation pressures.[1,22] Other significant complications, however, may be related to tourniquet use. Postoperative weakness, edema, stiffness, dysesthesia, and pain may be falsely attributed to surgical trauma or to lack of patient motivation if the clinician does not have an adequate index of suspicion of tourniquet-related neuromuscular injury.[11,23,24,27]

Randomized, prospective studies demonstrated electromyographic (EMG) abnormalities in 70% of lower extremities and in 77% of upper extremities surgically treated with a "routine" pneumatic tourniquet, compared with an incidence of 0% and 3.4%, respectively, in cases performed without the tourniquet.[4,18] These neurophysiologic changes may be associated with weakness of the involved extremity and a longer clinical recovery time, with postoperative EMG abnormalities persisting as long as five months in some cases.[4,18,25,30]

The tourniquet induces neuromuscular injury by causing ischemia in the tissues distal to the tourniquet, and by compression and ischemia in tissues beneath the cuff. Various investigators addressed effects of ischemia on muscle and nerve to define a "safe" period of

TABLE 1. Summary of Upper-Extremity Surgical Studies

Parameter	*8-cm-Wide Straight Cuff*	*8-cm-Wide Curved Cuff*
Number patients	15	14
Side operated		
Right	7	12
Left	8	2
Age (years)	53.1 ± 18.4 (23–77)	55.5 ± 17.9 (28–74)
Limb circumference (cm)	29.1 ± 3.2 (22–34)	30.7 ± 2.7 (25–35)
Systolic blood pressure (mm Hg)	127.7 ± 21.8 (100–180)	128.6 ± 13.8 (113–165)
Arterial occlusion pressure (mm Hg)	131.5 ± 32.2 (95–220)	129.9 ± 24.4 (90–175)
Cuff pressure used for case (mm Hg)	181.5 ± 32.2 (145–270)	186.0 ± 20.0 (155–225)
Tourniquet time (minutes)	110.2 ± 63.0 (4–251)	72.9 ± 37.1 (24–120)
Anesthesia		
General	4	3
Spinal	0	0
Epidural	0	0
Regional	8	6
Local	2	3
Unknown	1	2
Rating		
Excellent	12	8
Good	1	1
Fair	1	2
Poor	1	1
Not reported	0	2

Values are presented as mean ± SD (range).

TABLE 2. Summary of Lower-Extremity Surgical Studies

Parameter	*8-cm-Wide Straight Cuff*	*8-cm-Wide Curved Cuff*	*12-cm-Wide Curved Cuff*
Number patients	11	10	10
Side operated			
Right	5	8	5
Left	6	2	5
Age (years)	38.5 ± 17.0 (23–74)	45.3 ± 12.9 (29–65)	45.6 ± 19.0 (28–79)
Limb circumference (cm)	53.9 ± 4.3 (44–60)	50.5 ± 6.4 (42–62)	55.5 ± 6.6 (47–70)
Systolic blood pressure (mm Hg)	128.8 ± 27.8 (90–170)	121.2 ± 19.8 (100–165)	118.4 ± 14.1 (95–140)
Arterial occlusion pressure (mm Hg)	148.9 ± 37.5 (100–200)	142.3 ± 21.7 (116–175)	142.2 ± 35.5 (90–200)
Cuff pressure used for case (mm Hg)	218.0 ± 38.1 (166–280)	207.8 ± 32.7 (175–275)	197.2 ± 37.4 (160–275)
Tourniquet time (minutes)	58.1 ± 31.2 (13–114)	85.5 ± 38.0 (26–135)	57.7 ± 29.0 (24–105)
Anesthesia			
General	8	4	3
Spinal	2	4	6
Epidural	0	1	0
Regional	0	0	0
Local	1	0	0
Unknown	0	1	1
Rating			
Excellent	6	8	7
Good	2	0	1
Fair	1	2	1
Poor	1	0	0
Not reported	1	0	1

Values are presented as mean ± SD (range).

tourniquet hemostasis. Nerve and muscle injury are greater beneath than distal to the tourniquet, however, because of the combination of mechanical deformation and ischemia beneath the tourniquet.[19] Some investigators suggest use of the lowest possible tourniquet inflation pressure to minimize direct mechanical deformation.[2,16,21,23]

Recommendations have evolved regarding the optimal tourniquet inflation pressure for a given surgical procedure. Some authors advise arbitrary pressures of 350 to 500 mm Hg for lower-extremity cases[28] and 250 to 300 mm Hg for upper-extremity cases.[6] Others recommend twice the systolic blood pressure,[9] or systolic blood pressure plus 30 to 100 mm Hg.[14,26] The cuff pressure needed to occlude arterial flow, however, is affected by factors such as systolic blood pressure,[29] limb circumference,[2,16,29] limb shape and local anatomy,[22] vascular status,[8,10] and the width of the applied tourniquet.[2,16,17] Some investigators recommend setting the tourniquet pressure according to a direct determination of the minimum cuff pressure needed to occlude blood flow.[21]

Standard (*i.e.*, rectangular) tourniquets are designed to fit optimally on cylindrically shaped limbs (Fig. 4), but human limbs may be conical, which can result in poor cuff fit or

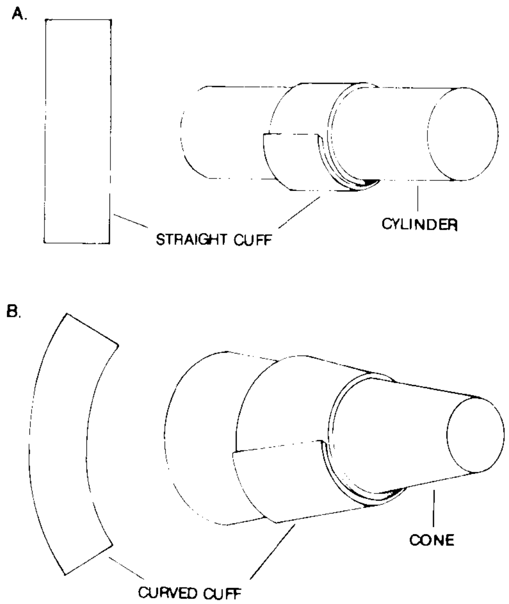

FIG. 4. Schematic representation of straight tourniquets (A) and curved tourniquets (B). Straight (*i.e.*, rectangular) tourniquets fit optimally on cylindrical limbs, while curved tourniquets are designed to fit on conically shaped limbs.

displacement of the cuff with inflation.[20,22] The curved tourniquet was designed to fit the conically shaped human thigh, and is particularly convenient to apply on extremely muscular or obese individuals (Fig. 4). It should be noted, however, that relatively uniform, longitudinal tissue pressure distribution was recorded beneath straight tourniquets on human anatomic specimen limbs[7,26] and on conical dog thighs.[14] Specific biomechanical differences between curved and straight tourniquets are unknown.[20]

The curved tourniquet occludes blood flow at a lower inflation pressure than a straight cuff of equal width, which may be attributable to better cuff fit and more efficient transmission of pressure to the deep tissues.[20] This difference was greater in the lower-extremity studies, which probably reflects the more conical shape of the thigh compared with the upper arm. An improved fit may cause increased contact area between the cuff and the skin, particularly at the distal cuff margin, making the curved cuff effectively a slightly wider tourniquet. Alternatively, the difference between the two cuffs may relate to the materials used for tourniquet construction, because the curved cuffs contain a stiffer reinforcing material exterior to the inflatable bladder than standard straight tourniquets.

Wide tourniquets occlude blood flow at lower pressures than narrow tourniquets on human arms and legs, which may be related to more efficient pressure transmission to the deeper tissues with a wider cuff.[2] In the current study, a wide curved tourniquet occluded blood flow at a significantly lower pressure than a narrower curved tourniquet. Pilot studies suggest that a wider curved cuff (for example, 15 cm) is associated with an even lower AOP. This cuff could be used during some lower-extremity procedures, particularly when knee exposure is not required.

The clinical technique described for determination of the AOP is similar to measurement of systolic blood pressure by auscultatory methods. This procedure requires less than five minutes to complete before surgery. The AOP determined by slow cuff-inflation-to-pulse-cessation should be the same as that determined by slow cuff deflation until flow resumes.[3] Either technique could be used with diagnostic equipment such as a Doppler flow meter, a PPG sensor, or pulse oximeter, which may be readily available in the operating room.

Tourniquet pressure was set at AOP plus 50 mm Hg in the current study. Reid *et al.*,[21] using standard tourniquets and a Doppler flow meter, noted cases of inadequate hemostasis during lower-extremity surgeries using this formula. Better hemostasis was achieved when the AOP plus 75 mm Hg was used for the lower extremities. In the current study, half of the cases with inadequate hemostasis had increased blood pressure after AOP determination, which was performed just after induction of anesthesia. This blood pressure change may relate to surgical stimulation or to fluid administration. Adding 75 mm Hg to the AOP may decrease the incidence of inadequate hemostasis during lower-extremity procedures. Arterial occlusion pressure could also be determined before induction of anesthesia (*i.e.*, before a drop in blood pressure), although this procedure may be somewhat painful. Tourniquet pressure may be adjusted during surgery according to changes in blood pressure, and adaptive tourniquet systems are described for this purpose.[13]

CONCLUSION

Curved and wide tourniquets occlude blood flow at lower inflation pressures than straight and narrower cuffs, respectively. The choice of tourniquet cuff width and shape should be individualized, taking into consideration the size and shape of the patient's limb and the specific demands of the operative procedure. An integrated cuff inflation system allows for direct determination of the AOP. Perhaps lower pressures could prolong the "safe" period of tourniquet compression. Because little information is available regarding pressure-time thresholds of neuromuscular injury in humans,[5,12] it is difficult to predict specific effects of a small decrease in cuff inflation pressure. Recent experimental studies[19] suggest that the magnitude of skeletal muscle injury beneath the tourniquet is related to complex interaction of the cuff pressure and duration. It seems logical to apply the lowest possible cuff inflation pressure to minimize neuromuscular injury induced by the pneumatic tourniquet.

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REFERENCES

1. Aho, K., Sainio, K., Kianta, M., and Varpanen, E.: Pneumatic tourniquet paralysis. J. Bone Joint Surg. 65B:441, 1983.
2. Crenshaw, A. G., Hargens, A. R., Gershuni, D. H., and Rydevik, B. L.: Wide tourniquet cuffs more effective at lower inflation pressures. Acta Orthop. Scand. 59:447, 1988.
3. Dahn, I., Lassen, N. A., and Westling, H.: Blood flow in human muscles during external pressure or venous stasis. Clin. Sci. 32:467, 1967.
4. Dobner, J. J., and Nitz, A. J.: Post-meniscectomy tourniquet palsy and functional sequelae. Am. J. Sports Med. 10:211, 1982.
5. Gelberman, R. H., Szabo, R. M., Williamson, R. V., Hargens, A. R., Yaru, N. C., and Minteer-Convery, M. A.: Tissue pressure threshold for peripheral nerve viability. Clin. Orthop. 178:285, 1983.
6. Green, J. L.: Operative Hand Surgery, ed. 2, vol. 1, New York, Churchill Livingstone, 1988, p. 1.
7. Hargens, A. R., McClure, G., Skyhar, M. J., Lieber, R. L., Gershuni, D. H., and Akeson, W. H.: Local compression patterns beneath pneumatic tourniquets applied to arms and thighs of human cadavera. J. Orthop. Res. 5:247, 1987.
8. Jeyaseelan, S., Stevenson, T. M., and Pfitzner, J.: Tourniquet failure and arterial calcification. Anaesthesia 36:48, 1981.
9. Klenerman, L., and Hulands, G. H.: Tourniquet pressure for the lower limb. J. Bone Joint Surg. 61B:124, 1979.
10. Klenerman, L., and Lewis, J. D.: Incompressible vessels. Lancet 1:811, 1976.
11. Love, B. R. T.: The tourniquet. Aust. N. Z. J. Surg. 48:66, 1978.
12. Lundborg, G., Gelberman, R. H., Minteer-Convery, M., Lee, Y. F., and Hargens, A. R.: Median nerve compression in the carpal tunnel: Functional response to experimentally induced controlled pressure. J. Hand Surg. 7A:252, 1982.
13. McEwen, J. A., and McGrawm, R. W.: An adaptive tourniquet for improved safety in surgery. IEEE Trans. Biomed. Eng. 29:122, 1982.
14. McLaren, A. C., and Rorabeck, C. H.: The pressure distribution under tourniquets. J. Bone Joint Surg. 67A:433, 1985.
15. Middleton, R. W. D., and Varian, J. P.: Tourniquet paralysis. Austr. N. Z. J. Surg. 44:124, 1974.
16. Moore, M. R., Garfin, S. R., and Hargens, A. R.: Wide tourniquets eliminate blood flow at low inflation pressures. J. Hand Surg. 12A:1006, 1987.
17. Muirhead, A., and Newman, R. J.: A low-pressure tourniquet for lower limb surgery. Injury 17:53, 1986.
18. Nitz, A. J., and Dobner, J. J.: Upper extremity tourniquet effects in carpal tunnel release. J. Hand Surg. 14A:499, 1989.
19. Pedowitz, R. A., Gershuni, D. H., Schmidt, A. H., Fridén, J., Rydevik, B. L., and Hargens, A. R.: Muscle injury induced beneath and distal to a pneumatic tourniquet: A quantitative animal study of effects of tourniquet pressure and duration. J. Hand Surg. 16A:610, 1991.
20. Pedowitz, R. A., Rydevik, B. L., Gershuni, D. H., and Hargens, A. R.: An animal model for the study of neuromuscular injury induced beneath and distal to a pneumatic tourniquet. J. Orthop. Res. 8:899, 1990.
21. Reid, H. S., Camp, R. A., and Jacob, W. H.: Tourniquet hemostasis: A clinical study. Clin. Orthop. 177:230, 1983.

22. Rorabeck, C. H., and Kennedy, J. C.: Tourniquet-induced nerve ischemia complicating knee ligament surgery. Am. J. Sports Med. 8:98, 1980.
23. Sanders, R.: The tourniquet, instrument or weapon? Hand 5:119, 1973.
24. Sapega, A. A., Heppenstall, R. B., Chance, B., Park, Y. S., and Sokolow, D.: Optimizing tourniquet application and release times in extremity surgery. J. Bone Joint Surg. 67A:303, 1985.
25. Saunders, K. C., Louis, D. L., Weingarden, S. I., and Waylonis, G. W.: Effect of tourniquet time on postoperative quadriceps function. Clin. Orthop. 143:194, 1979.
26. Shaw, J. A., and Murray, D. G.: The relationship between tourniquet pressure and underlying soft-tissue pressure in the thigh. J. Bone Joint Surg. 64A:1148, 1982.
27. Sherman, O. H., Fox, J. M., Snyder, S. J., Del Pizzo, W., Friedman, M. J., Ferkel, R. D., and Lawley, M. J.: Arthroscopy—"No-problem surgery." J. Bone Joint Surg. 68A:256, 1986.
28. Smith, H.: Surgical techniques. *In* Edmonson, A. S., and Crenshaw, A. H. (eds.): Campbell's Operative Orthopaedics, ed. 6. St. Louis, C. V. Mosby, 1982, p. 2.
29. Van Roeckel, H. E., and Thurston, A. J.: Tourniquet pressure: The effect of limb circumference and systolic blood pressure. J. Hand Surg. 10B:142, 1985.
30. Weingarden, S. I., Louis, D. L., and Waylonis, G. W.: Electromyographic changes in postmeniscectomy patients. Role of the pneumatic tourniquet. JAMA 241:1248, 1979.