Tourniquet Paralysis[1]

R. W. D. MIDDLETON[2] AND J. P. VARIAN[3]
Royal Alexandra Hospital for Children, Sydney

The principles of the use of the limb tourniquet have been unchanged for over 100 years, but the details of the techniques involved have gradually altered. This paper describes the modern practice of the use of the limb tourniquet in Australia, estimates the incidence of complications and indicates the pressure which may be produced by the Esmarch bandage.

CLINICAL MATERIAL

OF necessity, a very large sample of procedures needs to be gathered to give a significant amount of information, as complications from the use of tourniquets are rare. Because of their rarity and the concern of the surgeon on these occasions, it was thought that *questionnaire* information was likely to be quite accurate. One hundred and fifty-one members of the Australian Orthopædic Association have supplied data.

TYPE AND SITE OF TOURNIQUET USED

Both the Esmarch bandage (Figure 1) and the pneumatic cuff tourniquet are in use (Table 1). There is a decided preference for the pneumatic cuff on the arm, but a significant number of surgeons still employ an Esmarch bandage, and this occurs to a greater extent in relation to the lower limb, where over 50% of tourniquets used are of this type.

It was thought impossible to quantify the applications to the various sites, so that the alternatives to the question about site were "usual", "occasional" and "never" (Table 1). Only 11% of surgeons apply an arm tourniquet below the elbow. There is greater diversity in respect of the lower limb. Although all surgeons except one use the area above the knee as their usual site of application, a considerable number use the calf and ankle as a need arises. Forty out of the 151 responding surgeons use no other sites than above the elbow and above the knee. Information concerning the duration of occlusion was not sought except when a complication occurred.

TABLE 1
Tourniquet Preference

Tourniquet type	Number of surgeons
Arm	
Pneumatic	125
Esmarch	12
Either	14
Lower limb	
Pneumatic	66
Esmarch	46
Either	39

Site of Application

	Usual	Occasional	Never
Above elbow	149	1	1
Below elbow	2	16	133
Thigh	150	1	—
Calf	5	78	78
Ankle	—	38	113

Number of Applications.—Retrospective and prospective counting of the number of tourniquets used is a task of such magnitude as to be practically impossible. An attempt was therefore made to gauge the order of the number of tourniquets used per week. Assuming a 45-week working year and knowing the number of years the surgeon had actively practised surgery, we obtained an estimated

[1] Read at the Combined Meeting of the Australian and New Zealand Orthopædic Associations, Queenstown, New Zealand, September, 1972.

[2] Honorary Orthopædic Surgeon.

[3] Orthopædic Registrar.

Reprints: Mr R. W. D. Middleton, North Shore Medical Centre, 66-80 Pacific Highway, St Leonards, N.S.W. 2065.

figure of 630,000 cases in the reported series. This is equivalent to approximately 200 tourniquets per surgeon per annum, a figure which falls well within a credible range. Further, it was estimated that there were 240,000 applications on the arm and 390,000 on the lower limb. The following deductions are based on these assumptions.

COMPLICATIONS

Most complications reported consisted of peripheral nerve damage (Table 2). The incidence was one in 8,000 with a somewhat

TABLE 2
Palsy Type

52 Arm Palsies	
1. Total (Radial, Median, Ulnar)	27
2. Radial nerve only	19
3. Median nerve only	2
4. Other	4
30 Lower Limb Palsies	
1. Sciatic	2
2. Lateral popliteal	15
3. Other	13

higher figure of one in 5,000 for the arm than that for the leg, which was one in 13,000. It has not been possible to decide whether the arm is more susceptible to paresis or whether recognition is easier in the upper limb.

TABLE 3
Palsies and Tourniquet Type

Total arm palsies	
Type of tourniquet	Pneumatic, 8 Esmarch, 19
Time of application	20 minutes to 2½ hours
Recovery	All recovered
Time of recovery	Few days to one year
Radial nerve palsies	
Type of tourniquet	Pneumatic, 11 Esmarch, 8
Time of application	15 minutes to 1½ hours
Recovery	One permanent palsy; all others full recovery
Time of recovery	Few days to 6 months
Lower limb palsies	
Type of tourniquet	All Esmarch
Site of application	Above knee, 27 Calf, 3
Time of application	30 minutes to 4½ hours
Recovery	Partial, 1 Full, 29
Time of recovery	Few days to 9 months

The arm palsies fell mainly into two distinct groups (Table 3), the largest being involvement of median, ulnar and radial nerves below the tourniquet. There was a slightly smaller group of isolated radial nerve lesions. Other cases included two median nerve lesions and four which could not be classified because of lack of description.

The arm palsies (Table 2) occurred both with Esmarch bandages and pneumatic cuffs. All patients made a full recovery after varying periods, except one who developed a complete radial nerve lesion which persisted. This followed the use of an Esmarch bandage for 40 minutes. The approximate average time for recovery was four to five months, although some palsies were "transient" and others required up to 12 months to disappear.

In the lower limb there were 30 reported nerve injuries, but the classification was not as precise as in the arm (Table 2). Thirteen cases were difficult to classify, largely because of lack of accurate information. There was one case of femoral and sciatic palsy after a forgotten tourniquet — the only one reported in the series. This tourniquet was found at

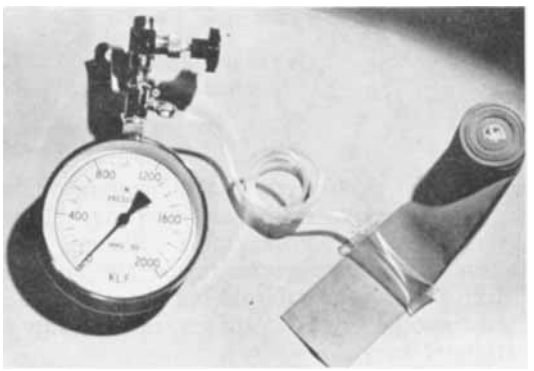

FIGURE 1

four and a half hours. It was removed when discovered, and the patient made a full recovery. None of the tourniquets were kept on for more than an hour and a half except the forgotten one. All reported complications followed an Esmarch bandage, except the single case of incomplete recovery which occurred many years ago when a tubing tourniquet had been used (Table 3).

Other Complications. — Various surgeons have attributed other mishaps to the application of a tourniquet. These have included death from cardiac arrest after bilateral leg exsanguination, and full thickness burns from a hot tourniquet. There was one case of femoral artery "spasm", with full recovery, and

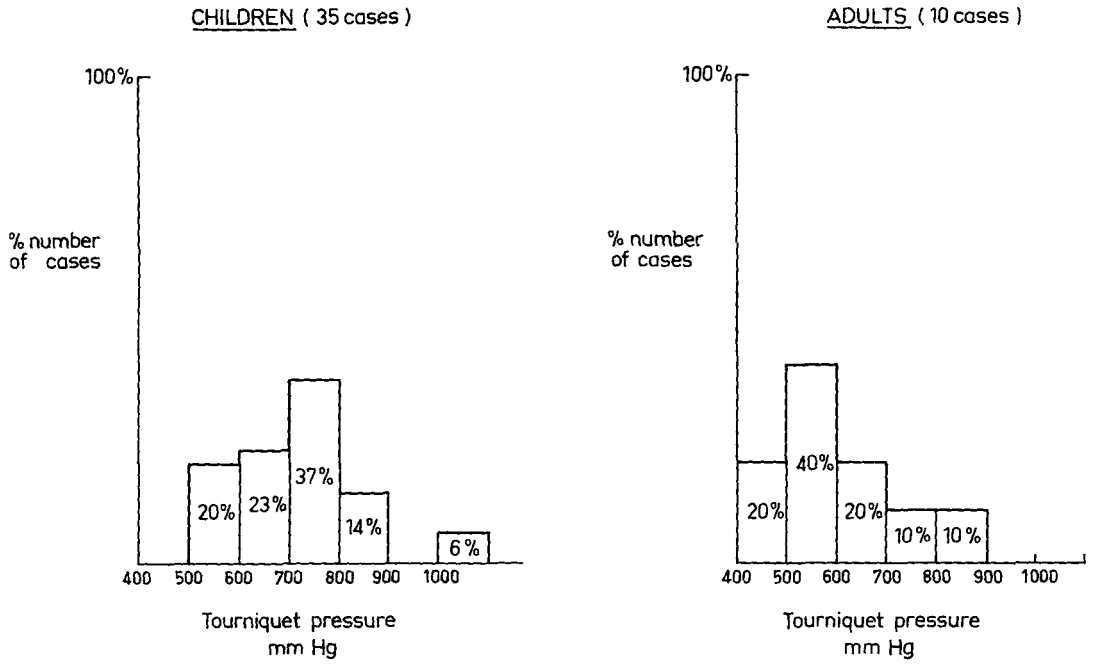

FIGURE 2

two cases of postoperative claudication, one of which was treated by bypass grafting. There was one case of Volkmann's ischæmic contracture. Eight surgeons raised the question of deep venous thrombosis. but there was lack of any specific evidence of its relationship to tourniquet usage.

Because of the apparent greater incidence of complications with the Esmarch bandage and the lack of knowledge of the pressures produced under it, a study was undertaken to determine those pressures.

METHOD

All tourniquets were applied in the mid-thigh region. At this level there are very few tendons. There is a single bone surrounded by muscle in three fascial compartments, with fat and skin coverage. Whereas the fascia and the skin strongly resist pressure from within, they cannot resist pressure from without, so that the thigh can be considered to obey the laws of fluid mechanics. Pressure is therefore distributed equally in all directions from external compression, and a small superficial pressure sensor accurately reflects deeper pressures.

Pressure is the function of force per unit area. With an Esmarch tourniquet, the force in the system is that used to stretch the bandage, but it acts radially over the area of application. The area is the product of the thigh circumference and the width of the tourniquet. As Esmarch bandages are of standard width, with superimposed layers of tourniquet the only variables in producing pressures are the force used to stretch the bandage and the thigh circumference.

Equipment.—A standard 3" red rubber Esmarch bandage was used. The sensor was a 3" × 1" Polythene bag made from Polythene sheet, connected

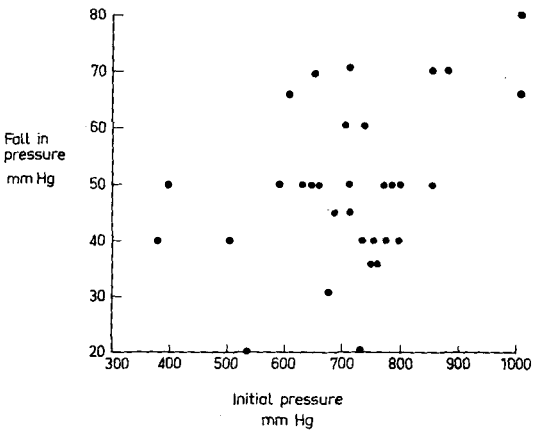

FIGURE 3

to the pressure gauge by Polythene tubing with an outer diameter of 4·5 mm and a bore of 3 mm. The pressure gauge was a standard Bourden tube gauge with a 6" gauge face (Figure 1). It was calibrated to 2,000 mm Hg full deflection. Accuracy was 1% of full scale. The Polythene bag, tube and gauge were filled with water to ensure that the sensor did not empty significantly under pressure. To allow easier filling of the system, the Bourden

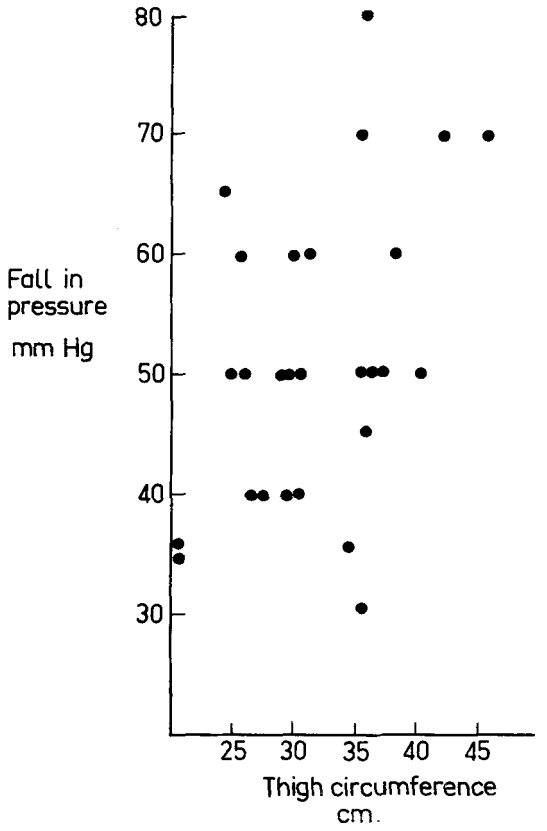

FIGURE 4

tube was reversed and a needle valve was included in the system. The readings were checked against those of the pneumatic tourniquet.

Forty children and ten adults admitted to hospital for lower limb surgery were studied. An Esmarch bandage was applied from the toes to the mid-thigh area to exsanguinate the limb, and was then maintained at the same level for six turns to form a tourniquet, with the Polythene bag included under the first turn. The gauge was always kept out of sight of the applier. The bandage was then unwound from the toes upwards to uncover the operation site. The tourniquet was applied by the same person using the same technique and, as far as he could tell, comparable force.

An attempt was made to measure the stretch force in the tourniquet during the application, but this failed because of inability to attach the gauge without tearing the rubber.

The circumference of the mid-thigh region was measured before application of the tourniquet. Pressure recordings were taken immediately after application, after 30 minutes, and at the end of the procedure before removal of the tourniquet. In five cases a reading was taken after each wind of the tourniquet during application. In children the mean pressure obtained under six turns was 710 mm Hg (Figure 2), varying from 510 mm Hg to 1,015 mm Hg. The mean pressure in adults was 585 mm Hg. In all cases there was a fall in pressure over the first 30 minutes, after which it remained steady. The fall varied between 20 and 80 mm Hg per hour. This fall bore little relation to the height of the initial pressure and no relation to the circumference of the thigh (Figure 4). On the five occasions when measurement was made after each turn the increase in pressure was found to be by arithmetical progression (Figure 5).

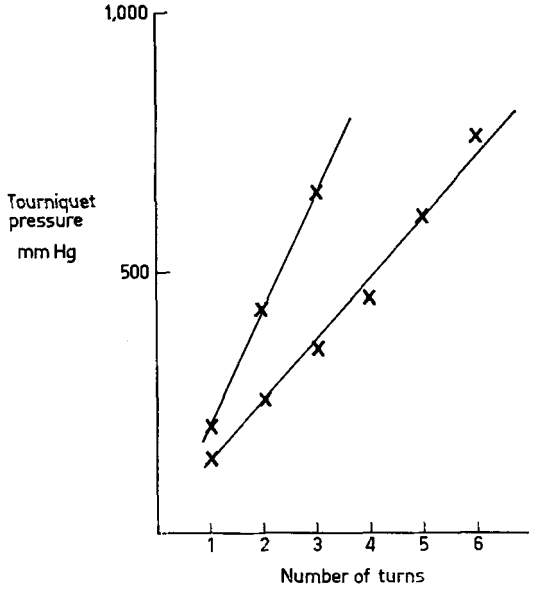

FIGURE 5

DISCUSSION

The pressure produced by the Esmarch tourniquet is variable, but is certainly greater than is generally appreciated. The difference between the pressures found in adults and children is a reflection of the differences in limb circumference. These findings are in accord with those of Griffiths and Hamilton (1970). There is a definite drop, not due to tourniquet loosening, in the first 30 minutes. It is suggested that this is probably due to the movement of extracellular fluid from under

the tourniquet and that this may be responsible for some tourniquet failures.

Variously, tourniquet complications have been stated to be frequent, and to be uncommon (Bruner, 1951; Eckhoff, 1931; Hamilton, 1967), but most reports have either been of sporadic cases, or have consisted of editorial comment, presumably based on the personal experience of the editor. The largest reported series of complications is that of Eckhoff (1931), who reported 14 cases, all in the upper limb. Moldaver (1954) added another seven, again all involving the upper limb. There have been no previously reported series of complications in the lower limb. The only estimate of the incidence of morbidity has been Flatt's (1972) report of two cases of nerve palsy in 1,500 operations.

In this series, despite the variation in the type of tourniquet used and the site of its application, the incidence of complications from its use has been extraordinarily small. In 630,000 applications the morbidity rate of one in 8,000 for peripheral nerve lesions indicates the safety of present techniques. This is further emphasized by the finding of only two permanent nerve lesions.

The Esmarch bandage has previously been blamed for most (Bruner, 1951; Eckhoff, 1931; Klenerman, 1962; Watson-Jones, 1957), if not all, tourniquet complications. That it carries a somewhat higher risk of morbidity than the pneumatic cuff is implied by the present series, but no exact definition of this has been possible, nor has it been possible to draw any conclusions regarding the cause of tourniquet paralysis. From the information obtained there is no apparent common factor. In the reported cases there was considerable variability in the period of tourniquet application and presumably in the pressures generated. It seems clear, however, that an uncontrolled Esmarch bandage can produce high pressures beneath it, and yet the incidence of nerve palsy is extraordinarily low. The evidence suggests that excessive pressure contributes to the peripheral nerve lesions, but the mechanisms involved are unclear. Undetermined factors may explain the apparent random distribution of this type of neuropathy.

SUMMARY

Complications follow the use of both Esmarch and pneumatic tourniquets as they are presently used, but this incidence is very low, and the lesions produced do not cause permanent disability.

REFERENCES

BRUNER, J. M. (1951), *J. Bone Jt Surg.*, 33A: 221.
ECKHOFF, N. L. (1931), *Lancet*, 2: 343.
FLATT, A. E. (1972), *Arch. Surg.* 104: 190.
GRIFFITHS, J. C., and HAMILTON, P. H. (1970), *J. roy. Coll. Surg. Edinb.*, 15: 114.
HAMILTON, W. K. (1967), *J. Amer. med. Ass.*, 199: 37.
KLENERMAN, L. (1962), *J. Bone Jt Surg.*, 44B: 937.
MOLDAVER, J. (1954), *Arch. Surg.*, 68: 136.
WATSON-JONES, SIR, R. (1957), "Fractures & Joint Injuries", fourth edition, vol. 1, E. S. Livingstone Ltd, Edinburgh and London: 121.

CORRIGENDUM

IN the article "The Use of Autopolymerizing Acrylic Cement in Osteosynthesis: An Experimental Approach", by Quazi M. Iqbal and M. Kannan Kutty (December, 1973), 43: 304-308, there appears in para. 1, p. 307, the statement: "Early systemic effects . . . except in those animals in which the total volume of blood lost had not been replaced (Harrington *et alii*, 1972)." The word "animals" should read "cases". We regret this error.