THE TOURNIQUET IN SURGERY

L. KLENERMAN, LONDON, ENGLAND

The early development of the tourniquet is bound up with the operation of amputation. It was only about a hundred years ago that the tourniquet was first used in other operations on the limbs. The introduction of the " bloodless field " is a landmark in the development of orthopaedic operative technique, and it is interesting to recall how this came about.

There is evidence that limbs were amputated as far back as the neolithic age, but only since Roman times have various constricting devices been employed to help the control of haemorrhage during amputation. Archigenes and Heliodorus, who practised in Rome at about the time of Celsus, used narrow bands of cloth placed directly above and below the line of incision, each passed two or three times about the limb and tied in a single knot. This mainly controlled the venous bleeding. It was an advance on the practice of Hippocrates, who recommended cutting through the dead limb at a joint, " care being taken not to wound any living part " (Adams 1849).

For the next 1,500 years no significant alteration appears to have been made in this practice. Ambroise Paré in the sixteenth century advocated tying " a strong or broad fillet like that which women usually bind up their haire withall " above the site of amputation (Johnson 1649). This helped to retain the maximum length of skin and muscle for the stump, controlled haemorrhage and reduced pain. The use of a stick to twist the constricting bandage was known to William Fabry of Hilden (1560–1624), although Morell in the siege of Besançon (1674) is often given credit for this (Fig. 1). In a work entitled *Currus Triumphalis e Terebintho* (1679), James Yonge of Plymouth gave an account of a similar contrivance produced by himself.

SCREW TOURNIQUET

Jean Louis Petit (1674–1750) (Fig. 4) described his invention of the screw tourniquet (Figs. 2 and 3) before the Academie Royal des Sciences in Paris in 1718. He was the first to use the name tourniquet, which is derived from the French *tourner*, to turn (Thompson 1942). This was a definite advance because it did not require an assistant to hold the instrument in place and could readily be released. The tourniquet consisted of a strap which passed around the limb and to which the screw portion was attached. When the screw was tightened pressure was brought to bear over the main vessel of the limb by a curved piece fixed to the screw. The screw was first made of wood and later of brass. Various modifications of Petit's apparatus remained in use until the latter part of the nineteenth century. However, during the Crimean War the British Army went back to the simpler variety of strap and buckle tourniquet (Thompson 1942).

LISTERIAN METHODS

Lister, about 1864, was probably the first surgeon to use the bloodless field for operations other than amputation. He described how his attention had been first directed to this subject when trying to work out a satisfactory method for excision of the wrist joint in tuberculosis, and overcome the profuse bleeding associated with the procedure. " And I found that when the hand was raised to the utmost degree and kept so for a few minutes and then while the elevated position was still maintained, a common tourniquet was applied to the arm being screwed up as rapidly as possible, so as to arrest all circulation in the limb and at the same time avoid venous turgescence, I had practically a bloodless field to operate on and thus gained the double advantage of avoiding haemorrhage and inspecting precisely the part with

FIG. 1

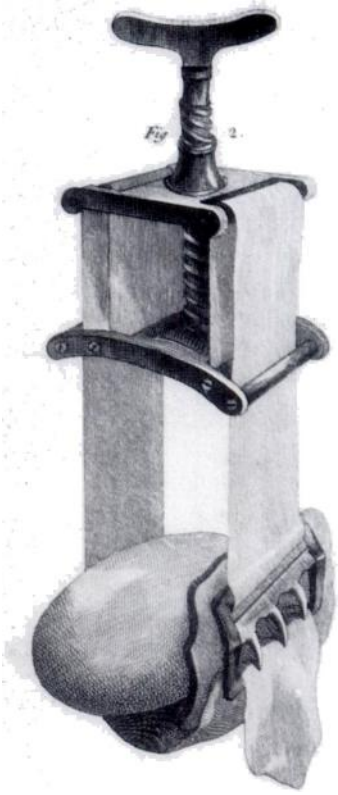

FIG. 2

Figure 1—Morell type of tourniquet (Seerig 1838).
Figure 2—Petit type of tourniquet (Savigny 1798).

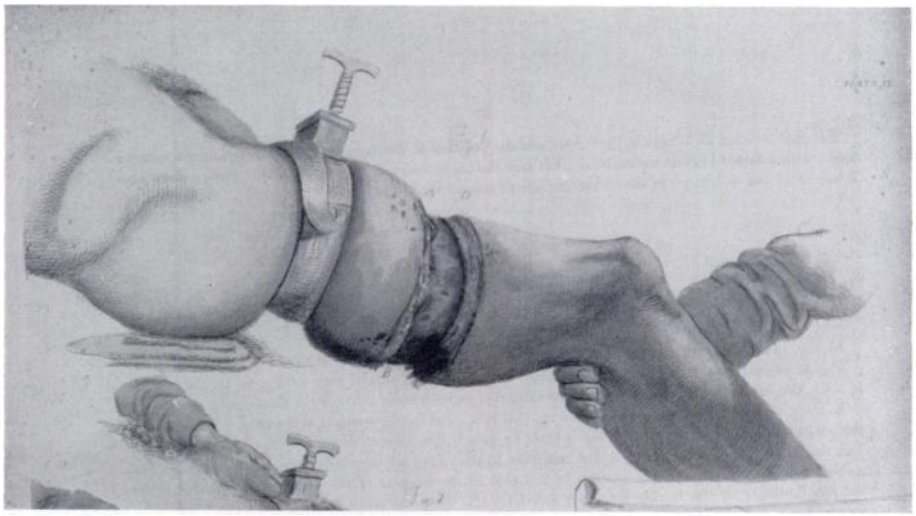

FIG. 3
Illustration from Sir Charles Bell's *Illustrations of the Great Operations of Surgery*, to show screw tourniquet in place.

which I was dealing." Lister emphasised the importance of elevation of the limb before the tourniquet was applied and considered four minutes to be the best time. There was thus drainage of all the venous blood and in addition an arteriolar constriction. He gave experimental evidence to prove this point, based on observations on his own hand, and on the exposed metacarpal artery of a horse.

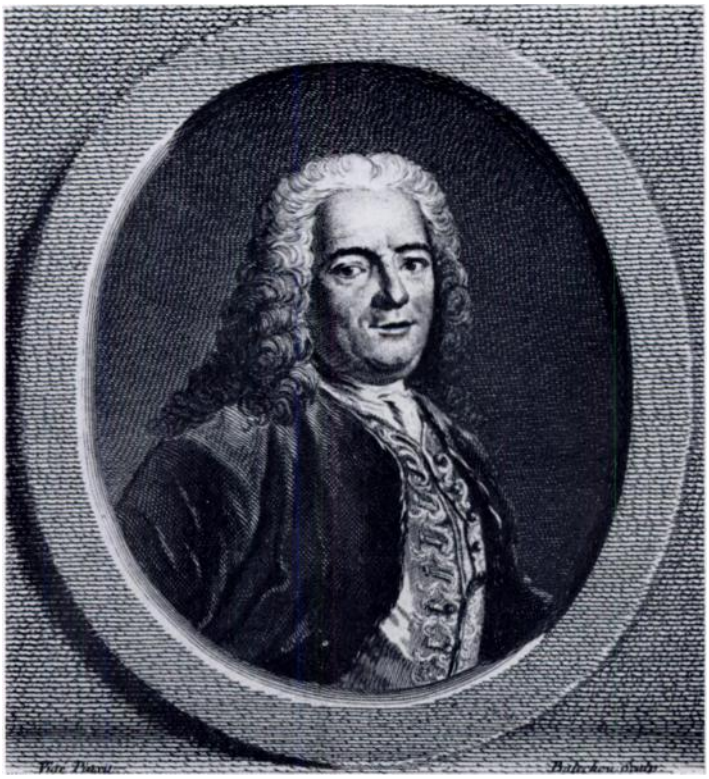

FIG. 4
Jean Louis Petit.

ESMARCH'S BANDAGE

The commonly used flat rubber bandage which was introduced by Johann Friederich August von Esmarch (Fig. 5), Professor of Surgery at Kiel, was first described by him in 1873. When Esmarch published his method of bloodless operation Lister changed from a tourniquet of the Petit type to Esmarch's rubber one because it was more trustworthy and more convenient, although throughout his practice he continued to empty a limb of blood by simple elevation (Godlee 1924).

Esmarch gave credit to Sartorius (1806), Brunninghausen (1818) and Sir Charles Bell in his book *Illustrations of the Great Operations of Surgery* (1821) for having used methods of expressing venous blood from a limb in combination with a tourniquet before him. He also acknowledged that Grandesso-Sylvestri in 1871 had used an elastic bandage for emptying a limb of blood before amputation. He himself had been bandaging limbs firmly before amputation since 1855. Esmarch had been stimulated to adopt this method in an effort to conserve blood because he had been disturbed at the amount of blood still present in an amputated limb after it had been severed from the patient. Subsequently he adopted the technique for other operations on the limb. He thus described an operation on a case of osteomyelitis of both tibiae.

" Both legs are then uniformly bandaged from the points of the toes to above the knee with elastic bandages, which are made of woven india-rubber, the uniform compression of which drives the blood out of the vessels of the limb. Immediately above the knee, where the bandage ends, we now apply the india-rubber tubing, well drawn out, four or five times about the thigh and connect one end with the other by means of the hook and brass chain attached to them respectively. . . . We now remove the bandage first applied and see both legs below the tubing resemble those completely of a corpse. You will observe that we operate precisely as in a dead subject."

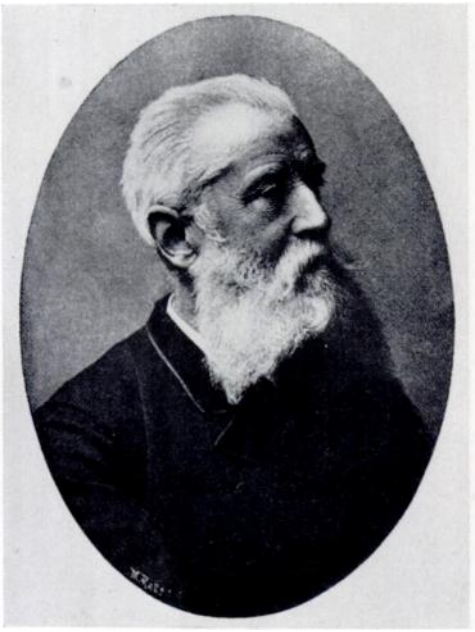

FIG. 5
Johann Friederich August von Esmarch.

At this time Esmarch had used the method in about eighty cases and had maintained ischaemia without ill effect for one hour. If, however, the soft tissues contained pus, the tourniquet was applied after elevation of the limb, compression with a rubber bandage being avoided as likely to spread the infection.

THE PNEUMATIC TOURNIQUET

Harvey Cushing introduced the pneumatic tourniquet to limb surgery in 1904. He abandoned the rubber tourniquet because it carried the danger of nerve palsy, and it was difficult to remove rapidly and re-apply during an operation. The idea of an inflatable cuff originated from the use of the distensible armlet of the Riva-Rocci blood-pressure apparatus. As this armlet could only be inflated slowly, it allowed the limb to become engorged with blood before finally rendering it ischaemic, and this made dissection difficult. Cushing thus designed a rubber cuff which could be quickly filled by connecting it to a large bicycle pump. As a refinement he suggested inserting a manometer in the tube connecting tourniquet to pump and a tank of compressed air to maintain the required pressure. Cushing also used a pneumatic tourniquet as a constricting band about the head to prevent loss of blood while a skull flap was being raised.

THE TOURNIQUET TODAY

Today in every reputable operation theatre a regular drill is followed when a tourniquet is used. The pneumatic tourniquet is the instrument of choice for both upper and lower limbs, although there is still a tendency to use Esmarch's bandages as tourniquets on the thigh. With the pneumatic cuff there is measurable control of the pressure exerted on the vessel wall—usually 250–300 millimetres of mercury in an adult—and there is also an even distribution. There are several variations of the sphygmomanometer cuff available.

With the Esmarch's bandage each turn adds to the pressure, and when the turns overlap crushing of a nerve or vessel may occur. Distally placed tourniquets, such as those around the ankle, are unsafe because of lack of soft tissues, and are best avoided. There is, however, a place for the digital tourniquet in combination with local anaesthesia. It is of interest to note that Esmarch recommended " for constriction of a finger, a rubber tube the size of a goose quill will answer."

Haemostasis in a bloodless field—Careful haemostasis has long been a tenet of sound surgery, and this applies equally when operating in a " bloodless field." When practicable—that is

with the exception of operations on large joints—the tourniquet should be released before the wound is closed. In this way haematomas can be prevented and there is some evidence that there is less pain in the post-operative period. In a fine procedure such as a nerve suture, release of the tourniquet is a vital step before the nerve ends are apposed, because a haematoma at the site of suture would greatly impair the result.

The time limit—Despite its common everyday use, there is a dearth of recorded experimental and clinical evidence for the length of time it is safe to maintain a bloodless field. Two hours is the most generally accepted upper limit, although individual surgeons vary considerably in their views. Some will not exceed one hour. Bunnell (1956) stated that in his experience when the tourniquet time exceeded two hours there was a degree of tissue reaction in the form of local induration at the site of operation. He advised a ten-minute " breathing spell " after an hour and a half, after which the tourniquet could be safely re-applied for a further similar period.

In vascular surgery, when clamps have been kept on the aorta for longer than four hours, ischaemic changes have followed in both lower limbs. Two hours as the longest time for the tourniquet to be in position, with a ten-minute " breathing spell " at one and a half hours, thus seems to be well within the margins of safety.

Experimental work on dogs has shown that the dangers of prolonged tourniquet ischaemia can be prevented by local hypothermia (Paletta, Willman and Ship 1960). This suggests a possible future development in clinical work. Two simple practical suggestions for keeping the limb with a tourniquet cool are the frequent irrigation of the operative field with cold saline and the avoidance of hot spotlights (Bruner 1951).

The tourniquet is also used in dealing with tumours of the limbs. There is evidence that dissemination of tumour emboli is reduced when biopsy or amputation for malignancy is carried out in a " bloodless field " (Peltier 1956). It is also necessary to have a tourniquet for the perfusion of limbs with chemotherapeutic agents (Creech, Krementz, Ryan and Winblad 1958).

HAZARDS OF THE TOURNIQUET IN PRACTICE

Because of the care taken and the widespread use of the pneumatic cuff, complications from the use of the " bloodless method " are now rare. A variety of cases of vascular or neurological damage following the use of tourniquets have, however, been reported.

Arterial spasm has resulted from the use of Esmarch's bandage and solid rubber bands as tourniquets. This has led to Volkmann's ischaemic contracture and even gangrene (Wallis 1901, Griffiths 1950, Watson-Jones 1952). Barnes and Trueta (1942) were able to produce long-standing arterial spasm in rabbits when they used tourniquets consisting of soft wire within a piece of rubber tubing, whereas with soft rubber tubing alone this spasm did not occur.

Occasional damage to large vessels may occur during operations with a tourniquet and pass unnoticed at the time. Webb-Jones (1955) described three cases in which aneurysms had developed after stabilisation of a foot. Scott (1955) recorded the formation of an aneurysm of the peroneal artery after an operation upon the ankle through a postero-lateral approach.

Tourniquet paralysis from pressure upon a nerve has almost but not entirely disappeared with the use of a pneumatic cuff. Whereas Eckhoff (1931) reported fourteen cases of tourniquet paralysis, only two cases are included in the Medical Research Council Report on Peripheral Nerve Injuries (1954). It is interesting that all Eckhoff's cases were in the upper limb. Moldaver (1954) reported seven cases, two of which had followed the application of a pneumatic tourniquet. He also pointed out that mild forms of tourniquet paralysis may easily be overlooked unless a careful examination of all the various modalities of sensation is carried out.

If there has been neglect in removing a tourniquet after operation, loss of a whole limb may follow. Experience has shown that after six hours the tourniquet should be amputated off. It seems justifiable, however, to remove the tourniquet if it has been left in position for less

than six hours. An attempt should be made to relieve any arterial spasm persisting after its removal, and it is wise to elevate and bandage the limb firmly and to transfuse with plasma to maintain the systolic blood pressure (Griffiths 1950). Shock follows the release of the tourniquet because of the massive loss of fluid from the circulation through the small vessels of the anoxic limb (Fine, Frank and Seligman 1944), and acute renal failure may occur.

THE TOURNIQUET IN FIRST AID

There is no place for the tourniquet as a first-aid measure for acute haemorrhage. Watson-Jones (1952) pointed out that more limbs have been lost by the use of the tourniquet than have been saved. It is a pity that the public have not been educated to know that severe haemorrhage from a limb injury can be effectively controlled by lying the patient down, elevating the limb and obtaining firm pressure over the wound with a well padded bandage. Too much stress has been laid on the " pressure points " of arteries, and even in the latest handbook of the British Red Cross Society and the St John Ambulance Association the use of a constrictive bandage is advised " if it is necessary to maintain indirect pressure for more than a short time." This may be " a narrow fold triangular bandage, elastic belt or brace, but it is preferable to use a rubber bandage about four feet long, and about two and a half inches wide with a tape attachment at the end for fastening." A recommendation such as this cannot be too strongly condemned.

It is pleasing to note, however, that Lord Taylor (1960) in a handbook, *First Aid in the Factory*, states that although factory first-aid boxes must contain a rubber or pressure bandage for use as a tourniquet, it should never be used " as it is not a first-aid measure." The official teaching at the Royal Army Medical College is also that the tourniquet has no place in first aid. Although the tourniquet is described in the current Training Pamphlet No. 3 it has been recommended that it should be deleted from forthcoming editions (Watts 1962).

Tourniquets applied by laymen are often ineffective and frequently harmful. In the case of venous haemorrhage an inadequately applied tourniquet merely results in exsanguination of the patient. A case of ruptured varicose veins is known, in which seven separate tight bands were wound at intervals around the limb, and the bleeding still continued.

CONCLUSION

The history of surgery is to a large extent written around the record of its technical advances. A pneumatic tourniquet is a humble instrument, when compared with many of the more complicated mechanical devices in the modern operation theatre. Nevertheless, it has played a significant role in making possible the precise operations of present-day orthopaedics. Simple tool though the tourniquet may be, its application carries many potential dangers, and it should only be entrusted to skilled hands.

I would like to thank Mr A. Rocyn Jones, Mr H. Jackson Burrows and Professor A. J. Harding Rains for their advice and helpful criticism.

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