The relationship between tourniquet pressure and underlying soft-tissue pressure in the thigh

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The Relationship between Tourniquet Pressure and Underlying Soft-Tissue Pressure in the Thigh

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ABSTRACT: Soft-tissue pressures in specimens of the lower extremities of cadavera, obtained following hip disarticulation, were measured directly beneath a pneumatic thigh tourniquet to establish the relationship between the tourniquet pressure and underlying soft-tissue pressure. It was found that the tissue pressure was consistently lower than the tourniquet pressure and that the percentage of tourniquet pressure reflected in the underlying tissue varied inversely with the circumference of the thigh. It was also found that the pressure decreased with increasing depth of the soft tissue.

CLINICAL RELEVANCE: The use of a pneumatic tourniquet is potentially associated with injury to underlying muscles, vessels, and nerves if excessive pressure occurs beneath the tourniquet. In order to minimize the risk of soft-tissue injury, the lowest tourniquet pressure that maintains a bloodless field should be used. A nomogram based on data generated in this experiment is provided as a guide to determining appropriate tourniquet pressures.

The use of a pneumatic tourniquet to produce a bloodless field is a well established practice in orthopaedic surgery, but is not without its complications. There may be either systemic effects related to the ischemia distal to the tourniquet[1,6,15,17] or local injury to muscles[13], vessels[3,11], and nerves[2,8-10,14] due to excessive pressure beneath the tourniquet, or both.

Since injury to soft tissue beneath a tourniquet appears to be a direct effect of applied pressure[7,10,13], and since unduly high pressures may produce injury more rapidly[13], the lowest pressure that maintains the objective of a bloodless field should be used. As noted by Klenerman and Hulands[5], there has been little study on the appropriate levels of pressure that should be used in pneumatic tourniquets. This experiment was undertaken to determine the relationship between the tourniquet pressure and the pressure in the underlying soft tissue. With this information, it is hoped that the arbitrary selection of unnecessarily high tourniquet pressures will be eliminated, and that an informed selection will be made based on knowledge of the transmitted tourniquet pressure and the patient's blood pressure.

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Method

Four hip-disarticulation specimens were obtained from fresh cadavera. All specimens were of good quality and were free of vascular disease by gross inspection. All were maintained in a frozen state prior to use and were thoroughly thawed before testing. A range of extremity sizes was selected to correspond to those found commonly in clinical practice. The thigh circumferences, measured fifteen centimeters proximal to the superior pole of the patella with the knee in extension, were thirty-four, forty-four, forty-six, and forty-nine centimeters.

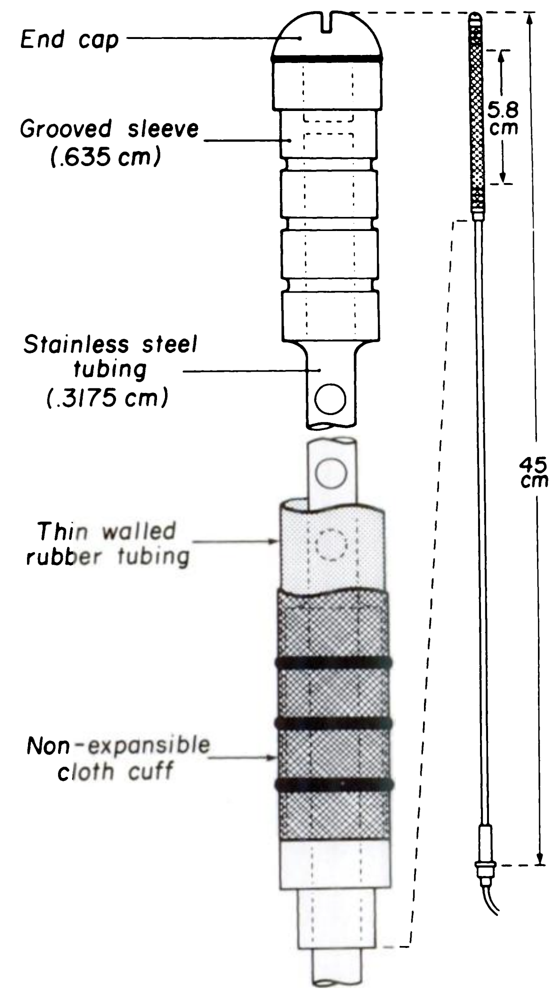

FIG. 1

Schematic representation of pressure probe.

A pressure probe was constructed to measure soft-tissue pressures beneath a tourniquet (Fig. 1). A fluid-filled chamber, composed of a thin-walled rubber tube (Penrose drain) surrounded by a non-expansible cuff made of cloth, served as the sensing portion of the probe. This portion of the probe was 5.8 centimeters long and 0.635 centimeter in diameter, and was located at the end of a stainless-steel tube that was forty-five centimeters long and 0.3175 centimeter in diameter. Hydraulic communication between the fluid-filled rubber tubing and the stainless-steel tubing was established through multiple small drill-holes in the stainless-steel tube. All air could be flushed from the probe and interconnecting tubing through a removable cap at the end of the probe. The rubber tubing was covered by a relatively non-expansible (but easily compressible) cuff made of cloth, to provide a pressurized hydraulic chamber of constant volume that could be subjected to an uneven distribution of external pressure without collapsing at the point of maximum pressure and expanding at points of lower pressure. This eliminated the potential for spuriously low pressure readings caused by collapse of the probe and blockage of the drill-holes. Since the rubber tubing-cloth composite had no significant structural rigidity in compression, any increase in surrounding tissue pressure was reflected directly as an increase in the hydraulic pressure within the probe.

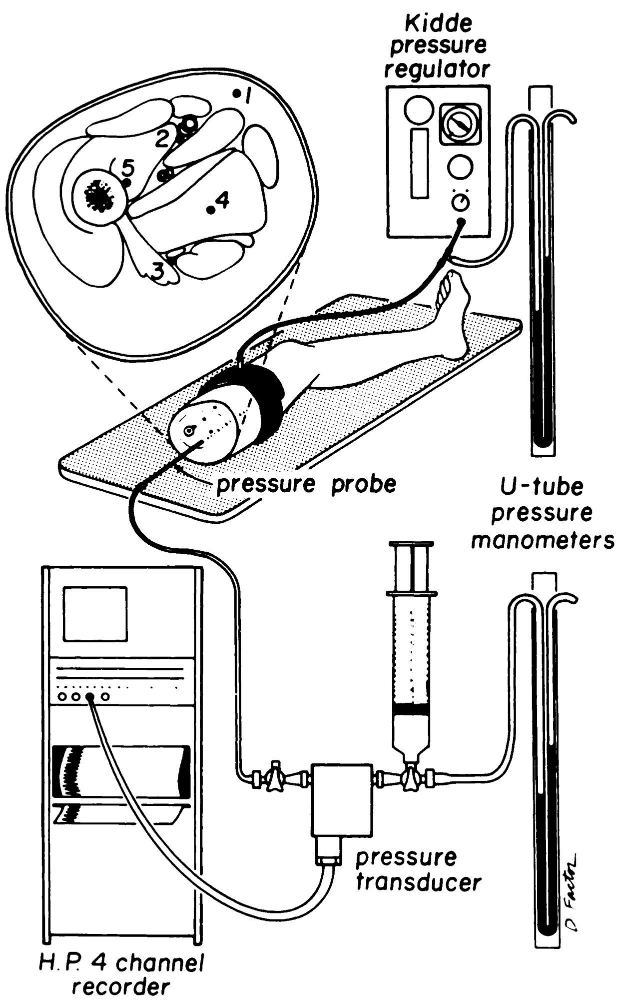

FIG. 2

Schematic representation of experimental set-up.

The pressure probe was connected to a Hewlett Packard (no.-267BC) pressure transducer by means of Luer locks and Cobe tubing. The output from the transducer was transcribed on a Hewlett Packard four-channel recorder (amplifier no. 8805B). Since the output of the transducer was "linear" over a limited range of pressures, the initial deflection of the transducer diaphragm due to the internal resting hydraulic pressure was "zeroed" with an equivalent pneumatic pressure on the other side of the transducer diaphragm. This pressure was recorded and maintained with a u-tube mercury manometer (Fig. 2). Any potential leak in the system could be easily and rapidly detected by either a shift in the zero position on the recording equipment or a change in the reading on the manometer, or both.

Pressure readings were recorded at five locations within the thigh (Fig. 2): (1) within the subcutaneous tissue, (2) immediately adjacent to the femoral artery, (3) immediately adjacent to the sciatic nerve, (4) within the muscle belly of the adductor magnus, and (5) adjacent to the femur on the medial side.

The pressure probe was inserted parallel to the femur and was positioned directly beneath the pneumatic tourniquet at each location. A standard Kidde (8.5 by eighty-six-centimeter) pneumatic thigh tourniquet was used. The tourniquet was placed around the thigh with the distal edge fifteen centimeters proximal to the proximal pole of the patella.

The tourniquet was pressurized with a Kidde regulator which was calibrated against a mercury manometer. Pressures were increased in increments of 100 millimeters of mercury, starting at 100 and ending at 900 millimeters of mercury. The soft-tissue pressures were recorded at each change of tourniquet pressure.

The pressure probe was calibrated against known pressures within a pressure chamber. The calibration was checked before and after pressure measurements in each extremity. There was no significant change in calibration throughout the experiment. Experimental error was estimated at ±10 millimeters of mercury, based on a combination of instrument error (small) and human error in extracting data from the strip recorder.

Results

The results of this experiment are represented graphically in Figures 3 and 4. The mean soft-tissue pressures (obtained by averaging pressures at all five monitoring locations) were consistently lower than the applied tourniquet pressures (Fig. 3). This difference in pressure was small in the thighs of lesser diameter but became increasingly apparent as the size of the extremity increased. The mean soft-tissue pressure reflected in the thigh that was thirty-four centimeters in circumference was 95 per cent of the applied tourniquet pressure. This decreased to 68 per cent in the thigh that was fifty-nine centimeters in circumference, with a nearly linear decrease between the two extremities (Fig. 4).

In all extremities, the soft-tissue pressure tended to decrease as the probe was advanced more deeply from the subcutaneous location toward bone. In the thigh that was thirty-four centimeters in circumference, the difference between the subcutaneous pressure and the pressure immediately adjacent to the femur was less than twenty millimeters of mercury. This difference in pressure remained relatively small in the thighs that were forty-four and forty-six centimeters in circumference, but increased markedly in the fifty-nine-centimeter thigh, particularly at higher pressures (Fig. 3).

Very little difference was recorded between pressures obtained at locations adjacent to the femoral artery, within the adductor magnus, and adjacent to the sciatic nerve. These pressures were generally less than the subcutaneous

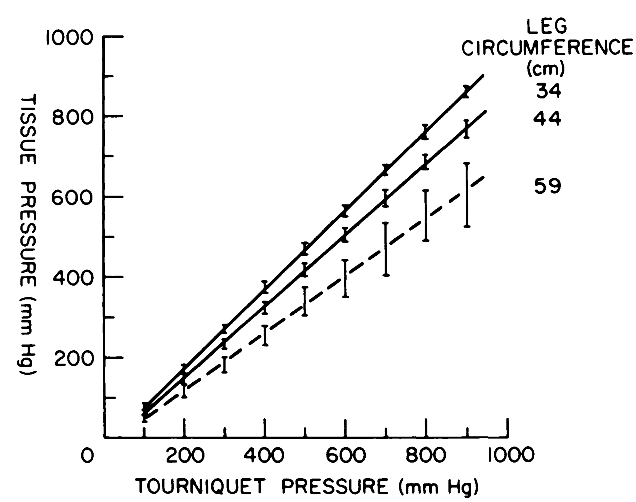

FIG. 3

Mean soft-tissue pressure as a function of applied tourniquet pressure for thighs of different circumferences. The vertical bars represent the difference between the subcutaneous pressure and the pressure adjacent to bone. Values for the forty-six-centimeter thigh are not shown in order to increase the clarity of the graph and avoid overlapping, but were consistent with the pattern shown.

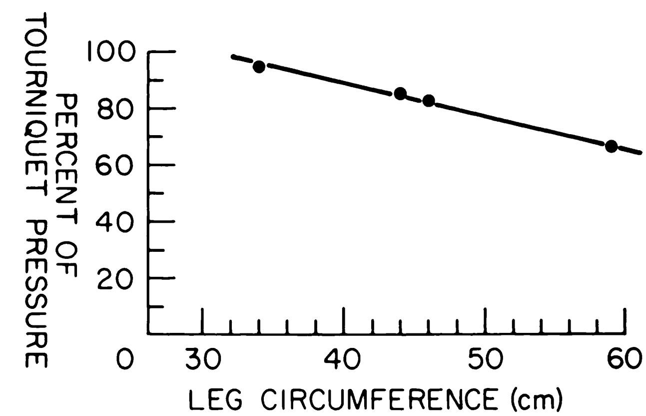

FIG. 4

Percentage of applied tourniquet pressure reflected in thighs of different circumferences (based on mean tissue pressure).

pressures and more than the pressures adjacent to bone. In one extremity the pressure probe could be inserted within the femoral artery. Pressure readings were similar to those adjacent to the artery.

Discussion

These findings are consistent with those of earlier investigators who have measured soft-tissue pressures beneath blood-pressure cuffs[16] or have compared intra-arterial pressure readings with those obtained from indirect measurements[12]. From these experiments, it is known that the blood-pressure cuff must be of appropriate width for the patient's arm or thigh in order to obtain an accurate pressure reading. According to the recommendation of the American Heart Association, the inflatable bag within a blood-pressure cuff should be 20 per cent wider than the diameter of the limb on which it is to be used[4]. If the cuff is narrower than the recommended width, the blood-pressure reading will be artificially high, as the pressure transmitted to the tissue is less than that within the cuff[4,16]. This effect becomes more pronounced as the size of the extremity increases or the width of the cuff decreases.

It is reasonable to expect that similar data would be found for pneumatic tourniquets. These must of necessity be narrow relative to the diameter of the thigh so that they do not interfere with the surgical exposure or the surrounding sterile field. One would expect, therefore, that the soft-tissue pressure would be considerably less than the applied tourniquet pressure. Moreover, one would expect the transmitted pressure to decrease as the extremity size increased for a constant tourniquet width.

Since pneumatic tourniquets have been associated with temporary or permanent damage to soft tissue, blood vessels, and nerves, it would seem reasonable in practice to limit the tourniquet pressure to a level that will provide hemostasis yet avoid unnecessary pressure on soft-tissue structures. On the other hand, care must be also taken to avoid the passive congestion and increased bleeding that result from underinflation of the tourniquet[18].

Rational decisions cannot be made regarding tourniquet pressures without knowing the pressure transmitted to the underlying soft tissues. For this reason, a nomogram based on data from the present experiment was constructed to aid in this determination (Fig. 5). The nomogram allows one to select an appropriate tourniquet pressure for a given circumference of the thigh and a desired tissue pressure. Since the systolic pressure during surgery may fluctuate considerably above the pressure that is present at induction of anesthesia, a soft-tissue pressure must be selected that is higher than the blood pressure at induction in order to maintain a bloodless field. We have found that a mean tissue pressure of seventy to 100 millimeters of mercury higher than blood pressure at induction of anesthesia will accommodate the expected fluctuations in pressure with a reasonable margin of safety and maintain a bloodless field under most clinical conditions.

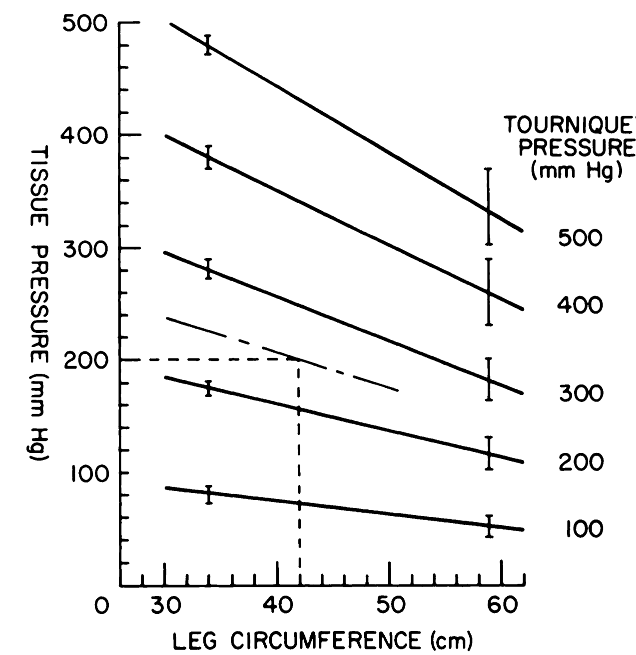

FIG. 5

Nomogram relating tourniquet pressure to underlying tissue pressure and thigh circumference. The sloping lines represent the mean soft-tissue pressures in thighs of different circumferences at given (constant) tourniquet pressures. The specific tourniquet pressure for each sloping line is indicated on the right margin of the nomogram. Tourniquet-pressure lines of intermittent value can be constructed by interpolation between the given lines. The vertical bars indicate the extremes of pressure that can be anticipated within a given limb from subcutaneous tissue to bone. This range of pressure varies with thigh circumference and tourniquet pressure, as shown.

In limbs of large circumference, the drop in pressure from subcutaneous tissue to bone may become of clinical significance in determining the appropriate tourniquet pressures. In these limbs, a higher mean tissue pressure will obviously be required to ensure a hemostatic pressure in the deeper tissue. The range of tissue pressures within a given limb is indicated by the vertical lines in Figure 5. This range varies with the circumference of the thigh and tourniquet pressure. As can be seen, the difference between the mean tissue pressure and the pressure adjacent to bone is relatively small except in large limbs at high tourniquet pressures. It has been our experience that in most patients the recommended range of mean tissue pressures of seventy to 100 millimeters of mercury higher than the induction systolic pressure will accommodate this factor as well. However, in obese patients with significant hypertension, correspondingly higher tourniquet pressures should be selected, in accordance with the tissue-pressure range indicated in Figure 5.

Use of the nomogram to select an appropriate tourniquet pressure in a clinical situation is illustrated by the dotted lines in Figure 5. In this hypothetical example, the circumference of the patient's thigh is forty-two centimeters and the patient's systolic blood pressure is 100 millimeters of mercury at induction of anesthesia. Based on the aforementioned considerations, a mean tissue pressure of approximately 200 millimeters of mercury is recommended to maintain a bloodless field. As shown by the dotted lines, these two coordinates intersect at a point approximately halfway between the tourniquet-pressure lines at 200 and 300 millimeters of mercury. An appropriate tourniquet pressure would, therefore, be about 250 millimeters of mercury.

As this example illustrates, interpolation is required to determine the appropriate tourniquet pressure if the intersection of the tissue-pressure and thigh-circumference coordinates occurs at a point between the given tourniquet-pressure lines. This can be done with sufficient accuracy by visually constructing tourniquet-pressure lines of intermediate values (as illustrated by the broken line in Figure 5).

As a further illustration, consider this patient's thigh circumference to be fifty-four centimeters (instead of forty-two centimeters). An appropriate tourniquet pressure would be approximately 300 millimeters of mercury. This is because the intersection of the soft-tissue pressure coordinate (200 millimeters of mercury) and the thigh-circumference coordinate (fifty-four centimeters) falls on the tourniquet-pressure line for 300 millimeters of mercury.

As a final example, if the patient's thigh circumference was forty-two centimeters (as in the original example) but a tissue pressure of 250 millimeters of mercury was desired because of a systolic blood pressure of 150 millimeters of mercury, the appropriate tourniquet pressure would also be 300 millimeters of mercury. As before, this is determined by the intersection of the tissue-pressure coordinate (250 millimeters of mercury) and the thigh-circumference coordinate (forty-two centimeters), which also falls on the tourniquet-pressure line for 300 millimeters of mercury.

As can be seen by inspecting this nomogram, tourniquet pressures of more than 300 to 350 millimeters of mercury would rarely be required in a normotensive individual with compliant vessels. Patients with morbid obesity, hypertension, or atherosclerotic vascular disease would, of course, require higher pressures to provide a bloodless field.

It is possible that living patients with incomplete muscle relaxation and a generally higher tissue turgor may require even higher tourniquet pressures than those suggested by this experiment on cadaver limbs. However, this has not been our clinical experience. Moreover, the data appear to suggest higher tourniquet pressures when compared with the clinical recommendation of Klenerman and Hulands[5] that the required occlusive tourniquet pressure can be estimated by doubling the blood pressure in the arm.

Conclusions

1. Pneumatic tourniquet pressures do not accurately reflect underlying soft-tissue pressures. The tissue pressure is consistently lower than the tourniquet pressure. The percentage of tourniquet pressure reflected in the underlying tissue varies inversely with the circumference of the thigh.

2. There is a tendency for the soft-tissue pressure beneath a pneumatic tourniquet to decrease with soft-tissue depth. This tendency is minimum with thin limbs but becomes more pronounced as the circumference of the limb increases.

3. A tourniquet pressure of more than 300 to 350 millimeters of mercury should rarely be required in a normotensive individual of normal habitus with compliant vessels.

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