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Wide tourniquet cuffs more effective at lower inflation pressures

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Longitudinal and radial tissue-fluid pressure distributions were determined beneath and adjacent to wide (12 and 18 cm) pneumatic tourniquet cuffs placed on intact human cadaveric arms and legs, respectively. Tissue fluid pressures exhibited relatively broad maxima at midcuff, and in most cases showed no differences at the various depths studied. Limb circumference was not a determining factor in the transmission of pressure to deeper tissue. We also investigated the effect of four cuff sizes (4.5, 8, 12, and 18 cm) on eliminating blood flow to the lower legs of normal subjects. The cuff pressure required to eliminate blood flow decreased as cuff width increased; thigh circumference was a determining factor in the pressure required to eliminate blood flow while using the smaller cuffs, but not while using the 18-cm cuff. Thus, wide cuffs transmit a greater percentage of the applied tourniquet pressure to deeper tissues than conventional cuffs; accordingly, lower cuff pressures are required, which may minimize soft-tissue damage during extremity surgery.

The tissue fluid pressure beneath pneumatic tourniquets varies widely. Using standard 8-cm cuffs, tissue pressures are consistently lower than the applied tourniquet pressure, and the transmitted pressure decreases with tissue depth (Shaw and Murray 1982, McLaren and Rorabeck 1985, Hargens et al. 1987). These findings imply that when tourniquets are applied to extremities of larger girth, higher cuff pressures are required to eliminate blood flow during limb surgery, thereby increasing the risk of damage to nerves and muscles (Ochoa et al. 1972, Klenerman 1980, Patterson and Klenerman 1979, Lundborg and Rydevik 1982). Newman and Muirhead (1986) have recently documented that a relatively wide 12.5-cm cuff is more effective at lower inflation pressures than a conventional cuff.

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The overall aim of our study was to develop a more effective system for providing a bloodless field during extremity surgery. Our first objective was to determine the pressures in tissues beneath relatively wide cuffs and to determine any influence due to limb circumference. Our second objective was to determine the relationship between cuff width and the cuff pressure needed to eliminate blood flow in the legs of normal subjects.

Methods

Cadaver study

Distributions of tissue fluid pressure were measured using standard pneumatic tourniquet equipment (Kidde Inc., Bloomfield, NJ, U.S.A.) in six intact arms (19–27-cm circumference) and six intact legs (33–46-cm circumference) of fresh human cadavera. The cadavera were refrigerated within 2 hours of death, and the study was performed 48–72 hours later. Cuffs measuring 12 and 18 cm in width were applied at midhumerus and midfemur positions, respectively. Steel tubes, 50 cm long and 1 mm in diameter were introduced through an incision just proximal to the elbow or knee and exited through an incision just distal to

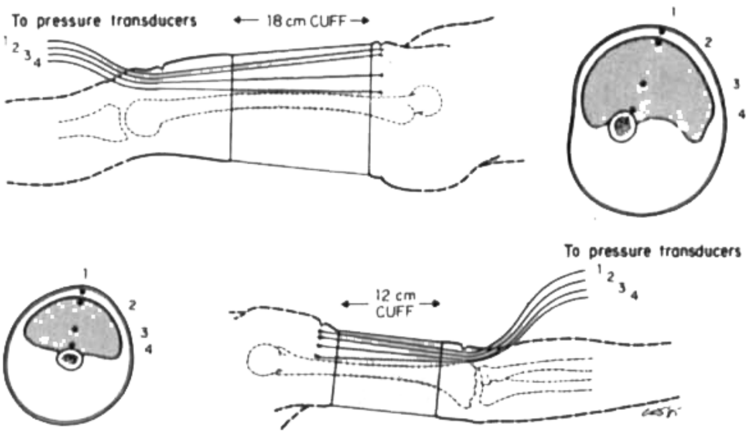

Figure 1. Longitudinal views of cadaver leg and arm showing placement of tourniquet cuffs and initial positions of catheters at four tissue depths: (1) subcutaneous, (2) subfascial, (3) midmuscle, (4) near bone. Cross sections of leg and arm show catheter depth within the limbs.

the shoulder or hip. The incision near the shoulder or hip was 10 cm long and extended from the skin to the bone. This allowed for inspection of the steel tubes thereby confirming their placement at the various depths for sequential studies at different cuff pressures. Slit catheters (Howmedica, Rutherford, NJ, U.S.A.), 60 cm long, were then threaded along the steel tubes proximally until the catheter tip appeared. The tubes were then removed through incisions at the shoulder or the hip (Figure 1).

The cuff was then inflated to a designated pressure, and the tissue fluid pressure was measured by low-volume displacement pressure transducers (Hewlett-Packard 1280, Waltham, MA, U.S.A.) and continuously monitored by a four-channel recorder (Hewlett-Packard 7754A). A 1-minute equilibration time was allowed for each position before taking a reading. Each catheter was withdrawn in 1-cm increments to measure the pressure sequentially from a point 2 cm proximal to the proximal cuff edge to a point 2 cm distal to the distal cuff edge. Upon completion of readings at a set cuff pressure, the steel tubes were reintroduced along the same paths and the catheters were reinserted. The cuff was then inflated to the next designated pressure. Cuff pressures for all the arms and legs were set at 200, 300, and 400 mgHg as calibrated by a mercury manometer. These pressures were chosen because they were most related to clinical cuff pressures for arms and legs. Tissue-fluid pressures of all the arms and legs were averaged and plotted at each longitudinal position and depth for each cuff pressure. To investigate differences with respect to tissue depth, midcuff tissue-fluid pressures at the four depths for each cuff pressure were analyzed statistically by one-way analysis of variance using Biomedical Data Processing Statistical Software (Dixon 1983). The effectiveness of transmission (percent of cuff pressure reaching the deep tissues near the bone) was calculated for the arms and the legs at all the cuff pressures. Limb circumference measurements were taken at the midhumerus and midfemur. To investigate the effect of limb circumference, tissue-fluid pressure nearest the bone was expressed as a function of limb circumference for arms and for legs and was analyzed by linear regression for each cuff pressure. Statistical significance was set at the $P < 0.05$ level.

Normal subject study

The pressure required to eliminate a pulse detectable by a Doppler device was determined for cuff sizes of 4.5, 8, 12, and 18 cm. Cuffs were applied to the left thigh of 6 females (43–65-cm circumference) and six males (31–57-cm circumference) with no history of vascular disease or previous leg surgery. The pulse was monitored at the posterior tibial artery just posterior to the medial malleolus using an ultrasonic Doppler device (Model 806-A, Parks Electronics, Beaverton, OR, U.S.A.). After the blood pressure was taken in the standard manner, the subject was placed in a supine position with the heel supported so as to avoid compression of the cuff by the bed. Cuff position was standardized by first placing the 18-cm cuff on the thigh, marking the boundaries, and then marking the midpoint between the two edges. The midpoint served as a reference for the center of all the cuffs and also the point at which circumference measurements were taken. Cuff sequence was randomly determined for each subject. After the first cuff was positioned, the point at which the Doppler pulse was maximum was determined and also used for all the other cuffs. The cuff was then slowly inflated by a Kidde automatic pneumatic system connected in parallel with a pressure transducer (Hewlett-Packard 1280) and a four-channel chart recorder. Inflation was continued at a rate of 10 mmHg/min until no pulse was detected. The pressure that eliminated a Doppler pulse was recorded from the chart recorder. The same procedure was used for the remaining cuffs. To investigate the effect of systolic blood pressure, cuff width, and circumference on the pulse elimination pressure, linear regression analyses (Dixon 1983) were performed. Statistical significance was set at the $P < 0.05$ level.

Results

Tissue-fluid pressure

The tissue-fluid pressure was always maximal at midcuff. A wider cuff on the legs led to a broader pressure plateau than in the arms even though the legs had greater circumference. Regional tissue-fluid pressures varied at 200, 300, and 400 mmHg with respect to the arms or legs (Figure 2). Maximal tissue-fluid pressures in the arms for all the depths were within 20–30 mmHg of the 200-mmHg cuff pressure, whereas those in the legs (18-cm cuff) were all within 20 mmHg of cuff pressure. Maximal pressure at various tissue depths were not different for the arms or legs.

At 400-mmHg cuff pressure, maximal pressures in the arms were within 30–90 mmHg of the cuff pressure, whereas those in the legs again were within 20 mmHg (Figure 2). Maximal pressures in the arms were higher in the subcutaneous and subfascial regions than near the bone ($P < 0.01$). However, pressures at various depths in the legs were not different.

The effectiveness of transmission (percent of cuff pressure reaching the deep tissue near the bone) ranged between 95 and 98 percent in the

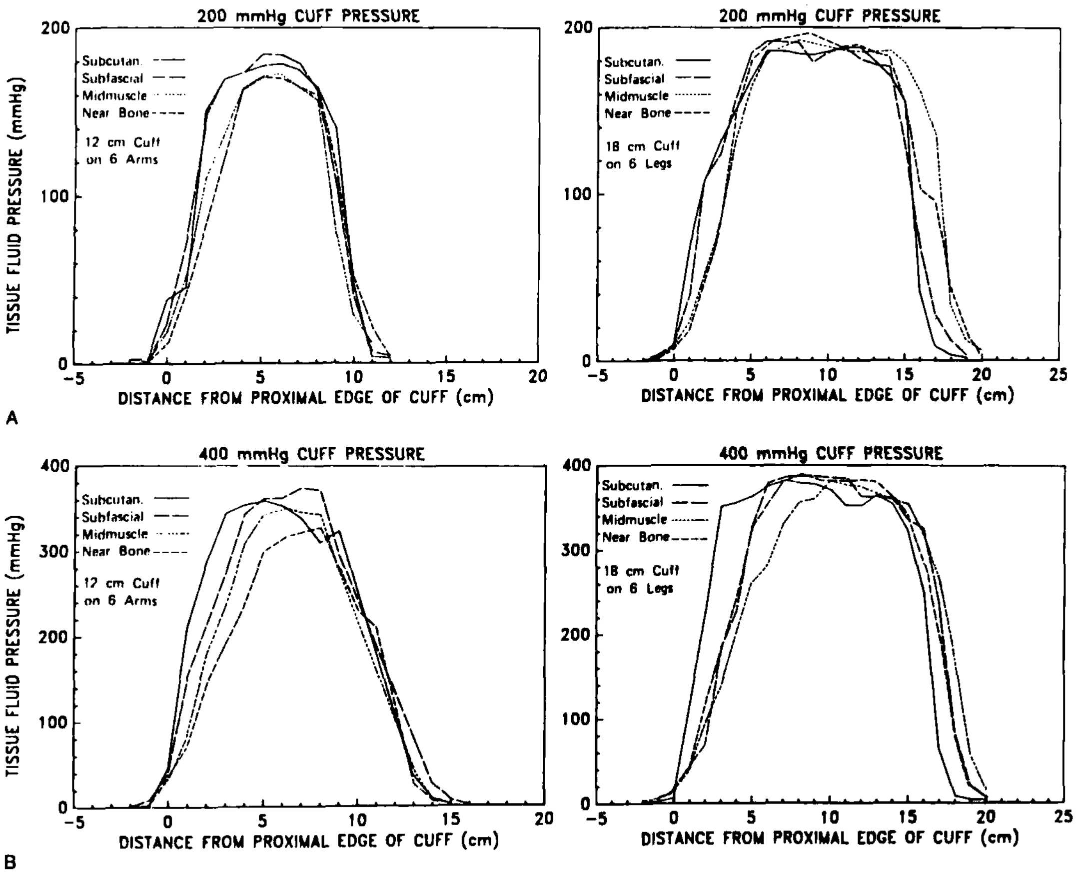

Figure 2. Distribution of tissue-fluid pressures in cadavers at four tissue depths beneath a 12-cm cuff on arms (left graph) and an 18-cm cuff on legs (right graph) applied at (A) 200 mmHg and (B) 400 mmHg.

legs using the 18-cm cuff and between 82 and 94 percent in the arms using the 12-cm cuff.

Further, using these relatively wide cuffs of 12 and 18 cm tissue-fluid pressure near bone did not decrease with greater limb circumference in the arms or in the legs.

Pulse elimination pressure

For all 12 normal subjects tested, the pulse elimination pressure was always highest when using the 4.5-cm cuff and lowest when using the 18-cm cuff. Overall, the pulse elimination pressure decreased as cuff width increased ($P < 0.001$), with good correlation between the pulse elimination pressure and cuff width (Figure 3). The equation for this relationship was as follows: Pulse elimination pressure = −9.9 (cuff width) +292.

Systolic blood pressure (110–113 mmHg) did not affect the pulse elimination pressure for any of the cuffs used.

The pulse elimination pressure was much more dependent on thigh circumference with the narrow 4.5-cm cuff and least dependent with the wide 18-cm cuff (Figure 4).

Discussion

Longitudinal pressure distributions in this study were consistent with previous work using standard 8-cm cuffs (McLaren and Rorabeck 1985, Hargens et al. 1987) in that the tissue-fluid pressure was maximized beneath midcuff. However, using 12- and 18-cm cuffs, maximal tissue-fluid pressure forms a wider midcuff plateau than that seen beneath standard clinical cuffs similarly placed on cadaver limbs (Hargens et al. 1987). The breadth of the pressure plateau is related to the cuff width. A previous study found a narrow peak of low maximal pressures using a standard 8-cm cuff (Hargens et al. 1987). All the maximal tissue-fluid pressures in our study were relatively high and nearly equal to the applied cuff pressure. When an 8-cm cuff is applied to legs with a cuff pressure of 300 mmHg, maximal tissue-fluid pressure decreases from subcutaneous tissue to tissue near bone (Hargens et al. 1987). Also the effectiveness of transmission for an 8-cm cuff is only about 64 percent compared with better than 95 percent using a wider cuff. In addition, wider cuffs require lower pressures than 8-cm cuffs in eliminating blood flow distal to the applied cuff.

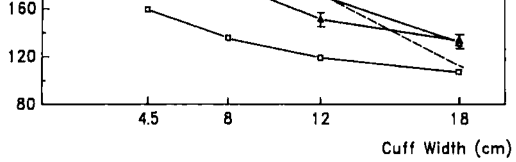

Figure 3. The relationship between pulse elimination pressure and cuff width. The middle plot represents the mean pulse elimination pressure (PEP) ± SEM for all the subjects (n 12). The top and bottom curves represent the largest (65 cm) and the smallest (31 cm) thigh circumference used in this study (note: the data point for the 65-cm thigh at the 4.5-cm cuff width exceeded the limitations of our measuring system, which was 360 mmHg). The dashed line represents a best fit linear regression, which was determined by using all the data points. Correlation coefficient *r* was = 0.71.

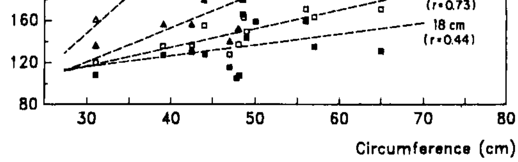

Figure 4. The relationship between pulse elimination pressure and circumference for the various cuff widths. Dashed lines represent a best fit linear regression corresponding to each width. Correlation coefficients are expressed as *r* values.

In a previous study, Moore and Hargens (1987) also used various cuff widths to eliminate blood flow as measured by a Doppler flow meter. Their results suggest that wider cuffs eliminate blood flow without total collapse of the arteries possibly due to an accumulation of frictional resistance to fluid flow along the compressed length.

Because most nerve injuries occur at the edge of the cuff where a marked pressure gradient occurs and tissue deformation is expected to be maximal (Rydevik and Lundborg 1977, Klenerman 1980), and because higher cuff pressures increase this pressure gradient, the lowest cuff pressure that creates a bloodless environment should be used. Although wider cuffs subject a greater mass of tissue to compression, the use of a lower cuff pressure may reduce the risk of underlying nerve injury. Newman and Muirhead (1986) found fewer postoperative paresthesias using the wider cuff and lower cuff pressures. Our experiment supports their clinical findings.

Using wide cuffs, limb circumference is not a determining factor in the transmission of pressure to the deep tissues. However, when Shaw and Murray (1982) applied an 8-cm cuff to cadaveric legs comparable in size to those in our study, a consistent decrease in the mean maximal tissue-fluid pressure was observed as circumference increased. Thus, they constructed a nomogram to determine the cuff pressure for a given limb circumference and a desired tissue pressure.

Based on their nomogram for a desired tissue pressure of 300 mmHg, the largest leg in our cadaver study would require a cuff pressure of 375 mmHg. However, using the 18-cm-wide cuff from our study, maximal tissue-fluid pressure is nearly equal to the cuff pressure of 300 mmHg; and therefore, a much lower cuff pressure can be employed. Further, the cuff pressure required to eliminate a Doppler pulse increased with limb circumference when using the 4.5-, 8-, and 12-cm cuffs, but not when using the 18-cm cuff. These findings suggest that cuffs wider than those used currently are more effective in providing a bloodless field over a wider range of limb sizes. Therefore, we recommend using as wide a cuff as possible for extremity surgery.

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