New finger cuffs for use with digital tourniquets

The advent of tourniquets employing digital technology has led to significant improvements in the safety and accuracy of surgical procedures performed with an occlusive cuff applied proximally on a limb. This article describes the evaluation of new cuffs used on fingers that may permit significantly lower pressures to be more safely and consistently employed. Our experimental studies would suggest that finger occlusion pressure is a function of cuff design, cuff width, finger circumference, and systolic blood pressure. (J HAND SURG 1988;13A:888-92.)

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I t is estimated that more than 250,000 surgical procedures are performed annually on isolated fingers by orthopedic, plastic, and trauma surgeons. For surgery on the isolated finger, occlusion of blood flow is typically achieved by a Penrose drain drawn tightly around the base of the proximal phalanx and secured with a hemostat,[1] by a Penrose drain used in the fashion of a miniature Esmarch bandage,[2] or by the use of a finger obtained from a surgical glove that is opened at the tip and rolled onto the finger from distal to proximal to exsanguinate the digit and leave a tight band at the base of the proximal phalanx.[3, 4] A disposable pneumatic tournique aimed at improving the application of occlusive pressure to fingers has recently been described.[5] Some specific complications associated with the finger tourniquets have been reported,[6-8] and it has been suggested that the actual complication rate is much higher than the incidence of cases reported in the literature.[9, 10]

The overall objective of our work was to develop for finger operations new cuffs that could be used in conjunction with digital tourniquets and to determine whether such cuffs might allow occlusive pressure on fingers to be established and maintained more safely,

more accurately, and more reliably than current techniques. When occlusive cuffs are applied proximally on limbs, it is known that the minimum limb occlusion pressure, i.e., the minimum pressure required to occlude blood flow into the limb, is a function of variables including cuff width and type, limb circumference, and the patient's ongoing systolic pressure.[11, 12] One specific objective of our work was to determine whether the finger occlusion pressure was similarly affected by such variables. If so, then another objective was to investigate this relationship, and if possible develop and evaluate guidelines that might assist the surgeon in (1) selecting a finger cuff having the maximum width that does not interfere with the specific procedure to be performed, (2) estimating the minimum finger occlusion pressure for that cuff as a function of the circumference of that finger and the patient's systolic blood pressure, and (3) estimating the minimum constant pressure that should be established in a digital tourniquet connected to that cuff. A final objective, if possible, was to consider how such cuffs might be employed as part of an automated system to establish and maintain the minimum finger occlusion pressure without the surgeon's intervention.

Structure and function of new finger cuffs

As shown in Fig. 1, a new finger cuff was developed, consisting in part of an inflatable tube of inextensible material with Luer-lock adapters at each end for attaching the tube to a pressurizing source and pressure sensor. The tube was formed by folding and sealing a rectangular segment of flexible thermoplastic laminate embedded with fine mesh (Herculite 10W fabric, Herculite Inc., N.Y.) to establish a collapsible tube of very flexible, inextensible material. For comparative evalu-
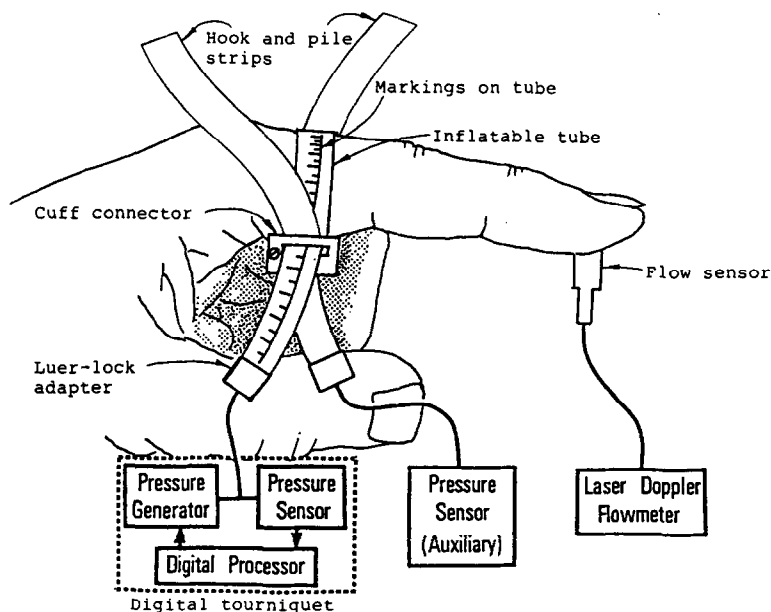
Fig. 1. New cuff attached to finger, with Laser Doppler Flowmeter employed to detect the onset of blood flow past the cuff.
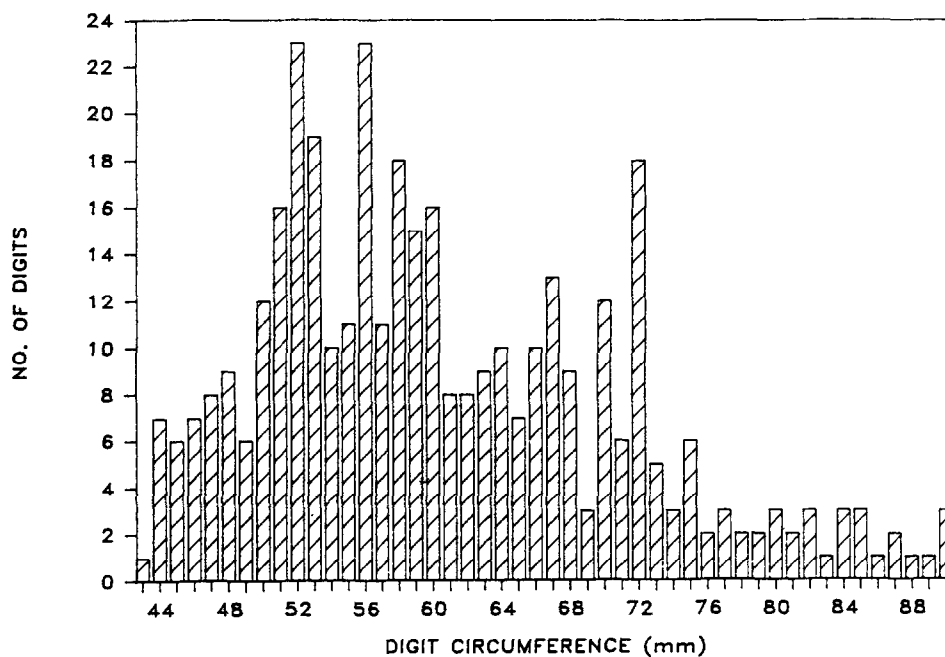

Fig. 2. Histogram of finger circumferences of all 20 fingers of 19 normal adults.

ation, other cuffs were made with tubes of soft, transparent vinyl. The transparent vinyl tube enables pinched tissue to be observed beneath the cuff, and the inextensible insert helps to stiffen one side of the tube and

direct inflation inwardly when wrapped around a finger. The tubes were marked with a graduated scale so that the finger circumference and cuff width could be determined visually (Fig. 1). The resultant tubes could
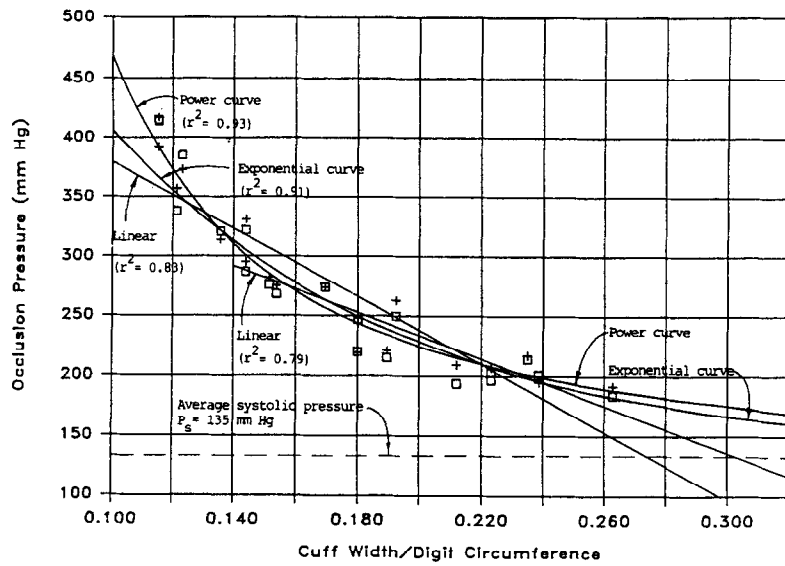
**Fig. 3.** Experimental data from fingers of the right hand of one subject (G. T.) fitted with the best straight line, exponential curve, and power curve. The power curve yielded the highest coefficient of determination (r^2). Results for other subjects were similar.
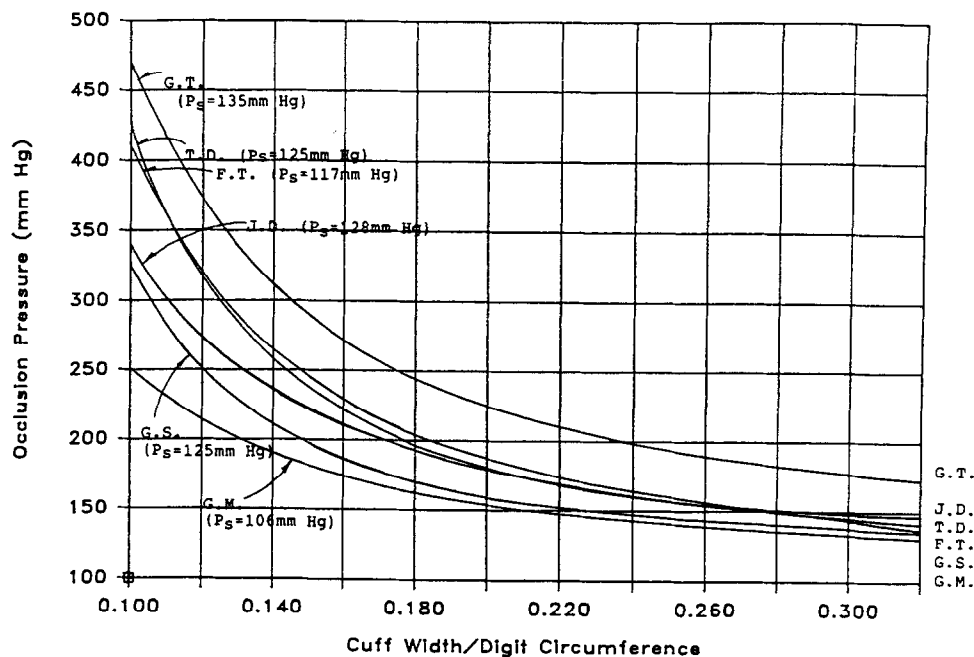
Fig. 4. Best-fit power curves for all experimental subjects, with the systolic blood pressure (P_s) noted for each, showing the relationship between finger occlusion pressure and the ratio of cuff width to finger circumference.

be drawn snugly around a patient's finger, conform closely to the finger, and present no sharp edges to finger tissue. These tubes withstood pressurization of up to 600 mm Hg while maintaining a pre-set diameter and length without significant stretching, ballooning, or leaking. As illustrated in Fig. 1, in the cuffs that were developed, the inflatable tube is secured around the finger by a cuff connector and fastener. The cuff
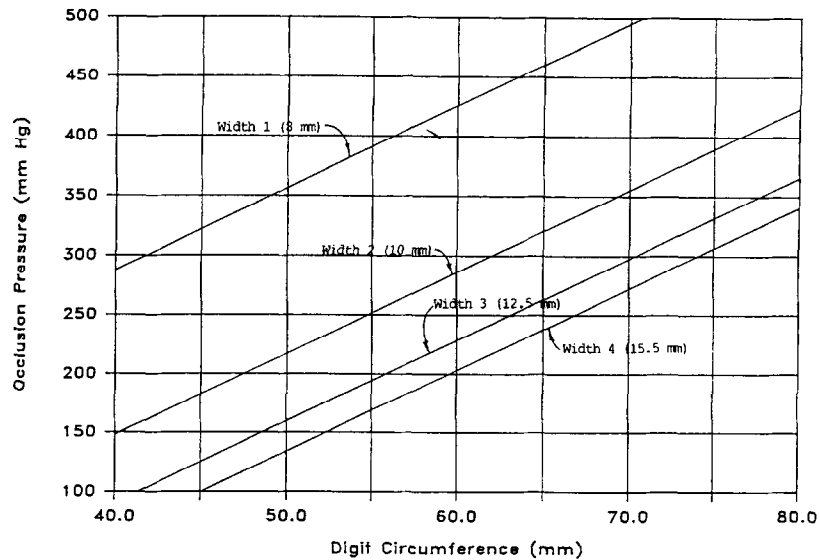
Fig. 5. Nomogram based on experimental data for estimating the minimal finger occlusion pressure for normotensive adult patients with nonhypertrophied, nonatrophied digits. The nomogram suggests that use of the widest practicable cuff permits the use of the lowest practicable finger occlusion pressure.

connector also provides a base for two hook-and-pile strips, which help direct inflation of the tube inwardly and provide a second, independent means of securing the tube around the finger. This combined securing method assures that, should either one of the tube-securing means malfunction, the other will retain the tube in position around the finger so that occlusion of blood flow will be maintained. Cuffs were fabricated with tubes of laminated material having widths of 8.0, 10.0, 12.5, and 15.5 mm. Cuffs with vinyl tubes having widths of 11.0 and 15.0 mm were also fabricated. All had lengths of approximately 10 cm, so that a normal range of finger circumferences could be accommodated.

In practice, a cuff is first selected, the cuff connector is released, and the tube of the cuff is positioned loosely around the finger. The tubing is then pulled through the cuff connector until the bladder is in snug contact with the finger around substantially all of its circumference. The cuff connector is then fastened shut, the auxiliary hook-and-pile securing means is fastened snugly against the tube, and the cuff is connected to a digital tourniquet similar to one of the Aspen Model ATS (Aspen Labs, Greenwood Village, Col.) tourniquets, and to an auxiliary pressure sensor if necessary (as shown in Fig. 1), so that the actual pressure in the cuff tube surrounding the finger can be monitored. The finger can be exsanguinated conventionally and the digital tourniquet activated to pressurize the cuff to a desired or predetermined value and thus occlude blood flow past the cuff.

Investigation

Initial tests were done on 19 normal subjects to obtain an estimate of the range of finger circumferences encountered in practice, and the results are shown in Fig. 2. Investigations were then done on six of these subjects. The subjects consisted of one female and five male volunteers, aged 20 to 36 years, with finger circumferences ranging from 51 to 75 mm, and with average systolic pressure ranging between 106 and 135 mm Hg. The prototype cuffs and cuff application technique described above were employed, in conjunction with a Periflux Model Pf2 Laser Doppler Flowmeter (Perimed Sweden, Stockholm, Sweden), with its sensor attached to the tip of the finger as illustrated in Fig. 1 to determine the onset of blood flow past the cuff. The primary objective of these investigations was to determine, for a given cuff design, how the minimum pressure necessary in the cuff for occluding blood flow into the digit might be affected by the circumference of the finger and the patient's systolic blood pressure. The Periflux Laser Doppler Flowmeter generates a signal proportional to the flux of blood cells within a hemisphere of 1 mm radius in tissue adjacent to the sensor placed at the tip of the finger; this flux signal approaches zero when blood flow is occluded. A Dinamap Model 845 Monitor (Critikon Inc., Tampa, Fla.), with a blood pressure cuff of acceptable width-to-circumference ratio was attached to the patient's right arm and was employed to estimate the systolic blood pressure by

oscillometry at 15-minute intervals throughout the tests. Details of the test procedures are given elsewhere.[13]

Results

Fig. 2 summarizes the measured circumferences of all 20 fingers of 19 normal adult subjects, measured at the middle of the proximal phalanx. The results show that finger circumferences varied between 43 mm and 90 mm in this typical normative sample. For individual subjects in the same sample, finger circumferences were found to vary by 34% on the hand and by 91% on the foot.

The results of the tests performed on the fingers of the hand of a typical subject using cuffs made of laminated material are shown in Fig. 3. The results of tests for all subjects are shown in Fig. 4. These results show a clear relationship between cuff width and finger circumference, and clearly indicate that, as with limbs, occlusion pressure in fingers is a function of the patient's systolic pressure and the ratio of cuff width to finger circumference for a given cuff design. Smaller width-to-circumference ratios mean that a higher pneumatic pressure must be employed to obtain occlusion of flow; conversely, lower pneumatic pressures can be employed in conjunction with wider cuffs, i.e., with larger width-to-circumference ratios. In surgical practice, this means that significantly lower applied pressures can be achieved by the use of the widest possible cuff that does not obstruct the surgical site.

Fig. 5 shows an alternate presentation of the results. The form is intended to assist in proposing guidelines for setting the optimal finger occlusion pressure for normotensive patients with normal, nonhypertrophied, nonatrophied fingers. In Fig. 5 an additional margin of 50 mm Hg was added to account for variables, such as the specific design characteristics of the type of cuff employed, variations in the preoperative and intraoperative systolic pressures of individual patients, errors in pressure regulation, and variations in techniques of cuff application.

To facilitate the clinical use of the new cuffs, a graduated scale of pressure markings based on the nomogram in Fig. 5 was added to each of the new cuffs, so that the surgeon can visually estimate the finger occlusion pressure when that cuff snugly encircles a normal finger of a particular circumference in a normotensive patient.

Discussion

Hazards and incidents may be associated with the use of pressures that are too high or too low in surgery of the isolated finger.

New cuffs have been developed that should permit the use of consistently lower and safer pressures for occluding blood flow for surgery of the isolated finger. When used in conjunction with digital tourniquets, these cuffs should provide occlusion safely, more accurately, and more reliably than the techniques that are typically used at present.

The results of our investigations indicate that it should be possible to employ occlusive pressures as much as 75% below the maximum that may be generated clinically by a Penrose drain and as much as 60% below the maximum pressure that may be generated clinically by the use of a rolled glove finger.[10, 14] In addition, it is possible for the surgeon to accurately monitor and reliably control the applied pressure through the use of these cuffs in conjunction with existing digital tourniquets.

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