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Wide Contoured Thigh Cuffs and Automated Limb Occlusion Measurement Allow Lower Tourniquet Pressures

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We examined the amount of thigh tourniquet pressure that can be reduced from the typical 300 to 350 mm Hg by using a new automated plethysmographic limb occlusion pressure measurement technique. We also examined how much pressure could be reduced by using a wide contoured cuff compared with a standard cuff and if limb occlusion and systolic blood pressures were well correlated. Patients having surgery with a thigh tourniquet were randomized into two groups, one group having surgery with a standard cuff and the other with a wide cuff. Pressure was set at the automatically measured limb occlusion pressure plus a safety margin. Systolic blood pressure and quality of the bloodless field were recorded. The standard cuff maintained an acceptable bloodless field for 18 of 20 patients at an average pressure of 242 mm Hg, and the wide cuff was acceptable for 19 of 20 patients at an average of 202 mm Hg. One patient in each group had a poor bloodless surgical field at the initial pressure, and one patient in each group had a poor bloodless surgical field after a sharp rise in blood pressure during surgery. Systolic blood pressure was not correlated well enough to limb occlusion pressure to be used alone to set the optimum cuff pressure. The automated limb occlusion pressure technique and the wide contoured cuff reduced average pressure by 33–42% from typical pressures.

Tourniquets maintain a bloodless surgical field allowing the surgeon to work with greater technical precision in a safe, clear environment.[9] Minimizing tourniquet pressure should reduce the risk of tourniquet-related injuries.[2,9,14,18] However, many surgeons still use a standard pressure based on experience, or they choose a cuff pressure using systolic blood pressure plus a standard margin or multiple.[8,20,23] In a recent survey, surgeons reported that they most commonly used thigh tourniquet pressures of 300–350 mm Hg.[8] These standardized pressures may be substantially higher than necessary for many patients, and insufficient for others. In addition, survey results show that many surgeons still used a standard-width cuff instead of the potentially safer wide contoured cuff,[8] which maintains a bloodless surgical field at a lower cuff pressure.[3,6,7,9,12,13,15,17]

Limb occlusion pressure is the tourniquet cuff pressure required to occlude blood flow and accounts for a patient's limb and vessel characteristics and the type and fit of the cuff. Limb occlusion pressure usually is determined by gradually increasing tourniquet pressure until distal arterial pulses cease, as indicated by a Doppler stethoscope,[5,10,11,19] or less commonly by a manually monitored plethysmographic signal.[17] Previous studies have shown that cuff pressure based on limb occlusion pressure measured on each patient before cuff inflation generally is lower than commonly used cuff pressures, but sufficient to maintain a satisfactory operative field.[5,10,17,19] However, based on survey results[8] and our experience, few surgeons use this technique, presumably because existing methods of measuring limb occlusion pressure require extra equipment, time, and a skilled operator to yield accurate results. Using systolic blood pressure plus a standard margin or multiple has been suggested[3,5,23] and would be easier, but the resulting cuff pressure seldom will be optimal because the relationship between limb occlusion pressure and systolic blood pressure is variable and dependent on vessel wall compliance, the size of the limb, the type of cuff, and other factors.[11,21] To make optimal cuff pressure setting more practical and more likely to be used by surgeons, McEwen et al[12,13] developed an automated plethysmographic system which can be built into the tourniquet instrument and can measure limb occlusion pressure in ap-

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The study protocol for human subjects was approved according to the relevant laws and policies of our institution; we obtained written informed consent from the subjects to participate in the study.
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proximately 30 seconds at the beginning of surgery. This new system was tested on volunteers in a laboratory setting and found to have similar accuracy when compared with the standard Doppler technique.[12,13]

In the current study, we examined the amount of thigh tourniquet pressure that can be reduced from the typical 300–350 mm Hg by using the new automated plethysmographic limb occlusion pressure measurement technique, the amount of pressure that can be reduced by using a commercially available wide contoured cuff versus a standard cuff, and if limb occlusion and systolic blood pressures were correlated well enough for systolic blood pressure alone to be used to determine optimal cuff pressure.

MATERIALS AND METHODS

A prototype photoplethysmograph sensor (similar to a pulse-oximetry sensor) and a handheld module containing the prototype hardware and software required for the limb occlusion pressure measurement functions were added to a standard Zimmer ATS 2000 tourniquet (Zimmer Patient Care, Dover, OH) (Fig 1). The operating software was modified, allowing the results of the limb occlusion pressure measurement to be shown on the standard ATS 2000 display panels, and the cuff pressure setting to be set to the recommended tourniquet pressure. Various error messages related to the limb occlusion pressure measurement also were displayed: weak signal, no signal, sensor off, and excessive sensor motion. Recommended tourniquet pressure was defined as the limb occlusion pressure reading plus 40 mm Hg for limb occlusion pressures less than 130 mm Hg, limb occlusion pressure plus 60 mm Hg for limb occlusion pressures between 130 mm Hg and 190 mm Hg, and limb occlusion pressure plus 80 mm Hg for limb occlusion pressures greater than 190 mm Hg.

The setup procedure is initiated by placing the photoplethysmograph sensor on the second toe. The cuff automatically inflates to 100 mm Hg and then deflates while the patient's pulse signal is detected and the sensor parameters are adjusted automatically. If a suitable signal is detected, the pressure is raised incrementally until the pulse signal in the toe ceases for four consecutive pulse intervals. The pressure increment is automatically reduced to a minimum of 5 mm Hg as occlusion is approached. The cuff is deflated again and the limb occlusion pressure is displayed along with the corresponding recommended tourniquet pressure. The tourniquet sets the cuff pressure to the recommended tourniquet pressure; however, the clinician can manually override this pressure setting at any time. This setup routine takes approximately 30 seconds.

All patients recruited for this study were adults scheduled to have foot and ankle procedures done by one surgeon (the first author) using a thigh tourniquet and either general or spinal anesthesia. All patients gave informed consent, and recruitment continued until complete data were obtained for 20 patients in each of the two cuff type groups. A standard 4-inch (10-cm) wide cuff (Zimmer ATS Cylindrical Cuff, Zimmer Patient Care) was compared with a 5.5-inch (13.8-cm) wide contoured cuff (Delfi Low Pressure Tourniquet Cuff, Delfi Medical Innovations Inc, Vancouver, BC, Canada) (Fig 2). At the time of cuff application, a wide or standard cuff was selected randomly by coin toss. The patients were blinded to the cuff selection but the surgeon was not. After administration of anesthesia and immediately before limb preparation and draping, systolic blood pressure was recorded and a plethysmographic limb occlusion pressure measurement was taken. The limb was prepared and exsanguinated by elevation and tensor bandage wrap, and the cuff was inflated to the recommended tourniquet pressure. At the surgeon's discretion, the cuff pressure was increased at any point in the procedure if required, and systolic blood pressure, time, and the reason for change were recorded. The surgeon rated the quality of the bloodless field as poor, fair, good, or excellent, and noted any changes in the quality of the bloodless field throughout the procedure. A poor field was one in which blood obscured the field, a fair field had blood present but not significantly interfering with surgery, a good field had some blood with no interference with the procedure, and an excellent field had no

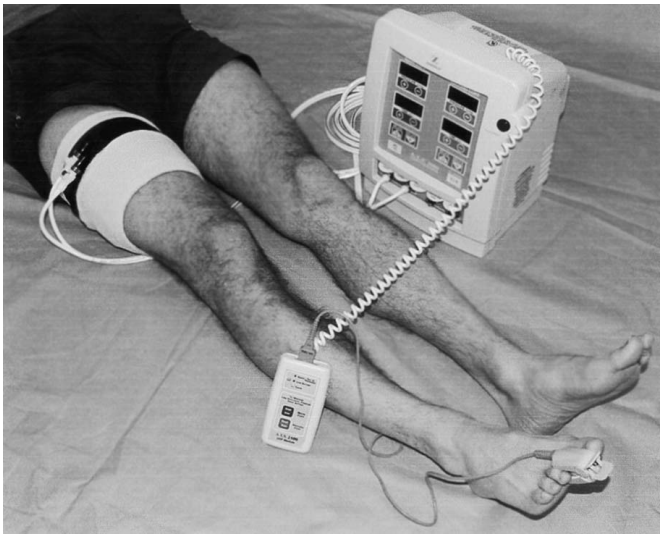

Fig 1. The automatic Limb Occlusion Pressure apparatus worn by a volunteer shows the sensor, prototype handheld limb occlusion pressure measurement module, modified tourniquet instrument, and wide cuff with limb protection sleeve.

Fig 2. This photograph shows the wide, contoured thigh cuff (top) and standard 30-inch cylindrical cuff (bottom).

blood present. Systolic blood pressure changes greater than 20 mm Hg during the procedure were recorded from the anesthesiologist's chart. Patients received the normal postoperative followup with no additional evaluation specific to this study.

To confirm that there were no significant gender and age differences between patients in the cuff type groups, a chi square and a t test (respectively) were used, with p values greater than 0.05 indicating the groups probably were similar in these respects. A t test assuming unequal variance was used to detect a difference in mean limb occlusion pressure between the standard and wide cuffs. Similarly, mean final cuff pressures were compared between the two cuff types. To confirm that the data were distributed normally, limb occlusion pressures and final cuff pressures within each cuff type group were checked using normal scores plots. If the data were distributed normally, nonpaired t tests were appropriate. Because of the relatively small sample size of 20 patients, variance estimates would have been approximate so unequal variances were assumed. To find correlation, limb occlusion pressure was plotted versus systolic blood pressure for each patient (each cuff type group plotted separately) and the coefficient of determination (r squared) for the best-fit line of each cuff type group was calculated. All statistical tests and correlations were done using Microsoft Excel 2000 (Microsoft, Seattle, WA).

RESULTS

Complete data were recorded for 20 patients in each cuff type group. Both groups of patients had similar gender proportions and average ages (Table 1). Of the 52 patients recruited, six patients were excluded because of incomplete data recording and use of an incorrect initial cuff pressure, and six patients were excluded because their pulse signals were too weak to make limb occlusion pressure measurements. The incidence of six patients in whom measurements could not be made indicates that efficacy of the system could be improved by increasing sensitivity, recognizing that it is not possible to use the system on every patient because of weak pulses, various digit deformities and conditions, or lack of digits on the involved limb. The three patients who had spinal anesthesia did not seem to have different results from the remaining patients who had general anesthesia; all three had good bloodless surgical fields throughout surgery at pressures near the group average. The patient who had spinal anesthesia in the standard cuff group reported cuff pain at 80 minutes tourniquet time. There were no unusual complications in the included patients that could be attributed to application of the tourniquet cuff. One of the patients excluded from the study because of a weak pulse signal had a diffuse nerve injury that may have been related to the cuff. In this patient, a pressure of 300 mm Hg with a wide cuff was used for 125 minutes. This patient had a previous nerve palsy from an operation as a child.

One patient in each group had a poor initial bloodless surgical field, a comparable incidence to that reported in the literature for various cuff pressure-setting techniques[5,10,17] (Table 1). For the patient in the standard cuff group, the recommended cuff pressure of 226 mm Hg was insufficient but was not changed. For the patient in the wide cuff group, the field was poor at the initial cuff pressure of 149 mm Hg; the pressure was raised to 250 mm Hg and the field became acceptable. Limb occlusion pressure may have been underestimated for these two patients.

One patient in each group had an acceptable bloodless surgical field at the recommended tourniquet pressure but had an unusually large increase in systolic blood pressure that caused the field to become poor late during the surgery (Table 1). For the patient in the standard cuff group, the field initially was acceptable at the recommended tourniquet pressure of 245 mm Hg but became poor when systolic blood pressure increased from 96 mm Hg to 140 mm Hg at the end of surgery (100 minutes tourniquet

TABLE 1. Patient Characteristics and Results Summary

	Patients	Gender	Age (Years)	LOP* (mm Hg)	FCP† (mm Hg)	Poor Field 1‡	Poor Field 2§
Standard cuff	20	7 females	Mean 46 (SD‖ 13, range 22–72)	Mean 178 (SD 33, range 124–254)	Mean 242 (SD 44, range 164–334)	1	1
Wide cuff	20	8 females	Mean 43 (SD 15, range 19–73)	Mean 142 (SD 28, range 94–183)	Mean 202 (SD 35, range 134–250)	1	1
p Value	—	0.09	0.53	0.0004	0.002	—	—
Statistical test	—	Chi square	t test	t test	t test	—	—

*Limb occlusion pressure

†Final cuff pressure

‡Poor fields at initial cuff pressure

§Poor fields after rise in systolic blood pressure during surgery

‖Standard deviation

time). For the patient in the wide cuff group, the field was acceptable at the recommended tourniquet pressure of 243 mm Hg but became poor when the anesthetic became light and systolic blood pressure increased from 124 mm Hg to 180 mm Hg after 40 minutes tourniquet time. Cuff pressure was not increased in either patient. These poor fields were related to anesthetic technique rather than efficacy of the limb occlusion pressure measurement system, and could have been prevented by maintaining more stable blood pressure or, less desirably, by using an unnecessarily high cuff pressure safety margin above limb occlusion pressure to accommodate blood pressure spikes.

Average thigh tourniquet pressures were reduced by 19–42% from the typical 300–350 mm Hg by using the new automated plethysmographic limb occlusion pressure measurement technique. The standard cuff maintained an acceptable bloodless field in 18 of 20 patients at an average pressure of 242 mm Hg. The wide cuff maintained an acceptable bloodless field in 19 of 20 patients at an average of 202 mm Hg (including the patient in whom pressure was increased to 250 mm Hg to correct an initially poor bloodless field). All but two standard cuff group final pressures were less than 300 mm Hg and all were less than 350 mm Hg. All wide cuff group final pressures were 250 mm Hg or less. Acceptable bloodless surgical fields were maintained at pressures as low as 164 mm Hg in the standard cuff group and 134 mm Hg in the wide cuff group (Table 1).

The wide contoured cuff reduced the mean limb occlusion pressure (Fig 3) by 36 mm Hg ($p = 0.0004$) and the mean final cuff pressure (Fig 4) by 40 mm Hg ($p = 0.002$) compared with the standard cuff. The t tests had an 80% accuracy in detecting a 25 mm Hg lower mean limb occlusion pressure and a 33 mm Hg lower mean final cuff pressure. The limb occlusion pressures and final cuff pressures in each group were distributed normally.

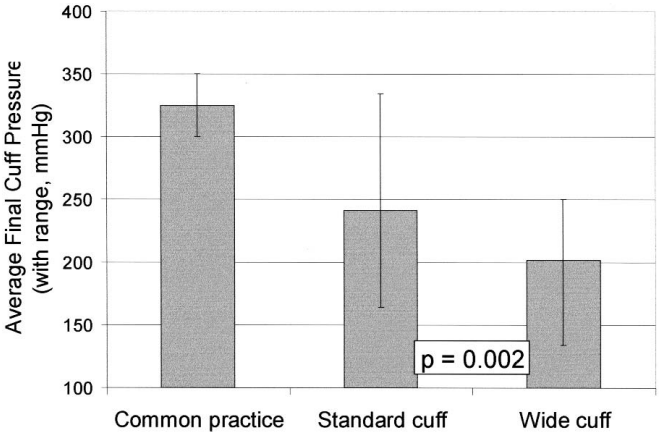

Fig 4. This graph shows the significantly lower average final cuff pressures for the wide contoured cuff compared with the standard cuff (n = 20 patients in each group) and with typically used pressures.

Limb occlusion and systolic blood pressures were not correlated well enough for systolic blood pressure alone to be used to determine optimal cuff pressure; linear correlation was weak in the standard and wide cuff groups (r squared 0.29 and 0.32, respectively),and there was no obvious nonlinear correlation for either group (Figs 5, 6).

DISCUSSION

The current study was designed to determine how much a new, more clinically practical approach to finding the op-

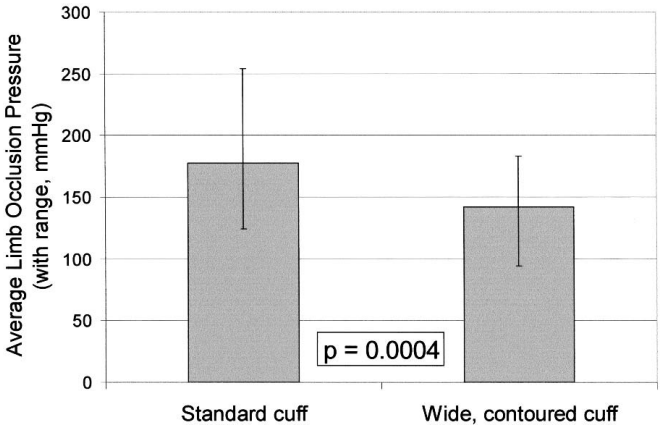

Fig 3. This graph shows the significantly lower average limb occlusion pressure for the wide contoured cuff versus the standard cuff (n = 20 patients in each group).

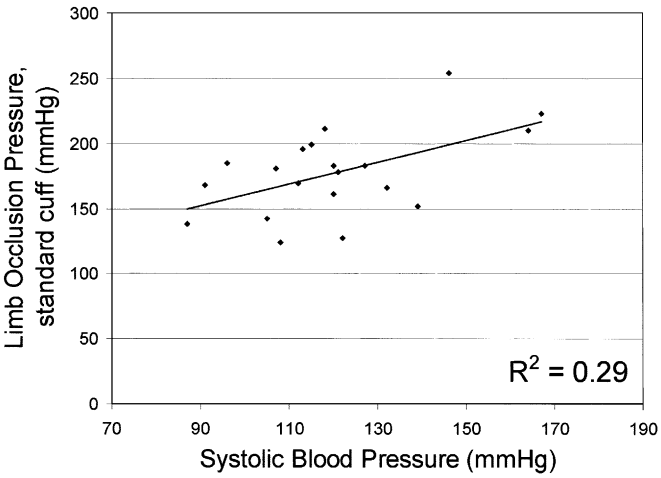

Fig 5. This graph shows the lack of linear correlation between limb occlusion pressure and systolic blood pressure in the standard cuff group (n = 20).

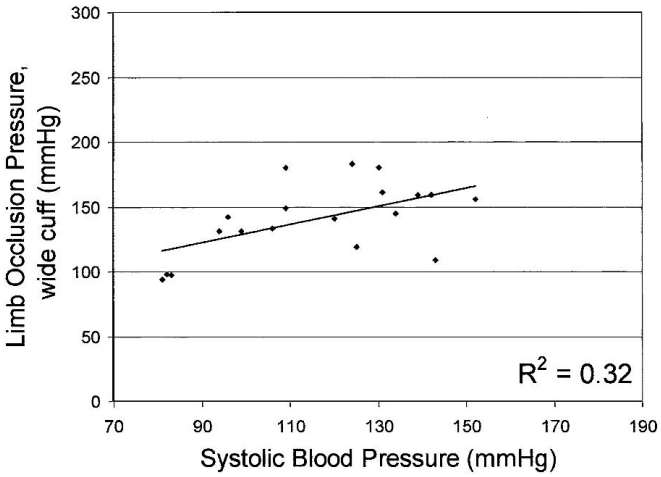

Fig 6. This graph shows the lack of linear correlation between limb occlusion pressure and systolic blood pressure in the wide cuff group (n = 20).

timal tourniquet pressure for each patient can reduce tourniquet pressure compared with pressures used during typical practice, how much additional reduction of pressure can be realized by using a wide contoured cuff compared with a standard cuff, and if the optimal tourniquet pressure can be predicted reliably from the systolic blood pressure alone. All patients scheduled for surgery during the current study were eligible and therefore should fairly represent the general surgical population. By randomizing the patients into two similar groups based on cuff type used, any additional reduction in average cuff pressure attributable to the wide contoured cuff alone could be found. Efficacy and ease of use were evident by direct observation of the bloodless field during surgery and the record of problems encountered during the study. The current study is the first to detail clinical use of a fully automated limb occlusion pressure measurement system for tourniquets, the first to provide clinical results using graduated safety margins based on limb occlusion pressure, and the first to provide a prospective randomized clinical comparison of a modern, commercially available wide contoured tourniquet cuff with a standard cuff.

The main limitation of this study is the subjective rating of the bloodless field by a surgeon who was not blinded to the cuff type. Although this rating is effective for identifying cases where the limb clearly is not fully occluded and is the method used in previous clinical studies of tourniquet occlusion, more subtle or transient differences in arterial seepage are not well detected. Another limitation is the prototype plethysmographic equipment, which caused the exclusion of some patients and may have skewed the study sample toward patients with stronger distal pulses. The current study was limited to patients having thigh cuffs and general anesthesia with only three patients having spinal anesthesia included, therefore the methods need to be further validated on upper limb procedures and other anesthetic techniques. However, we think our study provides a clear indication that the plethysmographic measurement system is effective and practical for most patients in the typical surgical setting, that substantial reductions in cuff pressures are possible, and that additional refinement and evaluation of the technique are warranted.

Reduction in cuff pressures will contribute to improved outcomes for extremity surgery; however, the clinical effect of these reductions in pressure may be hard to define. Before the use of modern tourniquet controllers, tourniquet complications often were catastrophic; currently, they are much harder to define. Sensory changes after surgery may be related to the surgery, the use of local or spinal anesthesia, or sympathetic dystrophy, and to tourniquet complications.

In a previous study on volunteers in a laboratory setting, McEwen et al,[12] found that that the wide contoured cuff used in the current study occluded arterial flow at an average of 49 mm Hg lower cuff pressure than the standard 4-inch wide cylindrical cuff, and that the plethysmographic technique used in the current study was within 10 mm Hg of the gold standard Doppler stethoscope results on most volunteers. McEwen et al,[13] reported similar results using a wide contoured lower leg cuff with the same plethysmographic limb occlusion pressure apparatus on volunteers. The current series resulted in a similar reduction (36 mm Hg) of limb occlusion pressure for patients who had the wide contoured cuff and for patients who had the standard cuff, and confirmed that the plethysmographic technique is practical and can be used safely during surgery to obtain a clear bloodless surgical field in most patients in whom a thigh tourniquet and general or spinal anesthesia are used. However the current series also showed that distal pulse signals were more difficult to detect in patients having surgery compared with volunteers in the laboratory setting.

Previous studies have shown that limb occlusion pressure can be used to optimize the cuff pressure required to maintain a bloodless surgical field.[5,10,11,17,19] Measurement of limb occlusion pressure directly at the time of cuff application takes into account variables such as the type and width of the cuff, the tightness of cuff application, the fit of the cuff to the limb, and the properties of the patient's soft tissues and vessels. However in practice, setting the cuff pressure based on limb occlusion pressure rarely is done, presumably because of the extra time and effort required. For example, only 7% of foot and ankle surgeons surveyed consider limb occlusion pressure when selecting cuff pressure.[8] Pedowitz et al[17] used a photo-

plethysmograph sensor signal displayed on a chart recorder and manually increased tourniquet pressure, reading limb occlusion pressure when the pulse signal disappeared, and found the procedure was effective and required less than 5 minutes per patient. However in our practice and presumably in many others, a 5-minute increase in operating room time is not acceptable for optimizing tourniquet pressure. The automated plethysmographic measurement system was developed to make limb occlusion pressure measurement at the beginning of each surgical procedure more clinically practical and acceptable; it is incorporated into the tourniquet instrument and requires only placement and removal of the sensor and activation of the automatic routine (approximately 30 seconds).

Cuff pressures of limb occlusion pressure plus a safety margin of 50–100 mm Hg to allow for changing conditions during surgery have been suggested, based on experience with poor bloodless fields.[5,10,17,19] Pedowitz et al[17] used a 50-mm Hg initial margin with various cuff designs and increased pressure as required during the procedure, resulting in an average margin of 53 mm Hg for arms and 64 mm Hg for thighs. Reid et al[19] found that Doppler limb occlusion pressure plus a 25-mm Hg safety margin did not provide adequate hemostasis, a 50-mm Hg safety margin provided adequate or good hemostasis for 44 of 44 upper extremity procedures but failed to occlude on two of 50 lower extremities, and a 75-mm Hg margin on the lower limb was adequate or good in 40 of 40 cases. Diamond et al[5] used a 50-mm Hg margin for ankle cuffs and found four of 54 fields were not bloodless. Leiberman et al[10] used a margin of 50 mm Hg on pediatric patients, resulting in inadequate hemostasis in one of eight upper limbs and initially 0 of 21 lower limbs, however three lower limbs became inadequate during the procedure and required cuff pressure increases to as much as 100 mm Hg greater than limb occlusion pressure. Based on these reported safety margins and the trend in these reports toward greater margins for lower limbs (which generally have higher occlusion pressures), we used margins of 40 mm Hg for limb occlusion pressure less than 130 mm Hg, 60 mm Hg for limb occlusion pressure of 130–190 mm Hg, or 80 mm Hg if the limb occlusion pressure was greater than 190 mm Hg. This new method of determining the safety margin allowed the system to automatically apply a greater margin to a limb with a higher occlusion pressure, thereby applying a 40–60 mm Hg margin to typical upper limbs and smaller circumference limbs (such as adult ankles and pediatric limbs) and a 60–80-mm Hg margin to typical thighs without requiring the operator to enter the limb type or size.

The incidences of poor bloodless surgical fields in the current study (two of 40 initially and an additional two of 40 attributable to sudden blood pressure rise later in the procedure) are comparable to those reported in the literature[5,10,17] with the exception of Reid et al[19] who had adequate or better bloodless surgical fields in every case. In the current study, the patient with the initial poor field in the wide cuff group had an occlusion pressure reading 34 mm Hg less than the systolic blood pressure. Although occlusion pressure may be close to the systolic pressure with wide cuffs,[7] in this patient the extremely low reading leads us to suspect a poor occlusion pressure reading caused by weak distal pulses which should have triggered an error warning. The initial poor field with the standard cuff occurred with a safety margin of 60 mm Hg and a cuff pressure 94 mm Hg greater than systolic blood pressure; this is the only case in which a poor bloodless field occurred without a suspected error in measurement or substantial rise in blood pressure. The two patients who had late bleed-through had safety margins of 60 mm Hg and relatively high (44 and 56 mm Hg) blood pressure increases. Based on these results, we think that the safety margins used are acceptable when anesthetic technique can maintain stable blood pressure, but we would not recommend lower margins. Adequate safety margins are important not only to prevent poor bloodless fields, but also to ensure adequate tourniquet pressure. Tourniquet injury can result from inadequate tourniquet pressure, which occludes venous return but allows arterial flow to enter the limb. The resulting engorgement of the limb may result in compartment syndrome and other complications possibly leading to loss of limb function.[11,16] Shaw and Murray[21] reported that some arterial blood flow may persist after a Doppler signal ceases and the same might be true with the plethysmographic signal used in the current study, therefore an adequate safety margin is essential to ensure complete occlusion and to compensate for changing conditions during the procedure.

Setting thigh cuff pressure based on systolic blood pressure plus a margin of 100 mm Hg has been suggested and reported to reduce cuff pressures and early postoperative thigh pain.[23] However, the limb occlusion pressure varied widely relative to systolic blood pressure in results from volunteers[12,13] and in our current clinical results. Other researchers have reported that the correlation between systolic blood pressure and limb occlusion pressure is not always strong, particularly for patients who are normotensive.[3,11,15] In the current study the resulting final cuff pressures used ranged from 45–188 mm Hg greater than systolic blood pressure (mean, 121 mm Hg; standard deviation, 37) with the standard cuff and 34–130 mm Hg greater than systolic blood pressure (mean, 85 mm Hg; standard deviation, 24) with the wide cuff. There was almost no linear correlation of limb occlusion pressure and systolic blood pressure (Figs 5, 6). Similarly, final cuff pressures did not have a strong linear relationship to systolic blood

pressure with either the standard or wide cuff (r squared, 0.33 and 0.53, respectively). This variability suggests that basing cuff pressure on systolic blood pressure alone does not lead to an optimum cuff pressure; for example, even with the strongest of these relationships (wide cuff pressure based on systolic blood pressure, r squared = 0.53), the resulting 95% confidence interval of a cuff pressure predicted from the systolic blood pressure is 147–254 mm Hg for the typical patient. To accommodate this variability, the margin over systolic blood pressure required to obtain the same number of acceptable bloodless fields has to be large, thereby increasing average tourniquet pressure. Systolic blood pressure is only one variable affecting limb occlusion pressure, whereas limb occlusion pressure inherently accounts for variables such as tourniquet cuff design, application method, limb circumference and shape, and tissue characteristics at the cuff site.

Previous studies have shown that wide and wide contoured tourniquet cuffs occlude flow at lower pressures than narrower cuffs.[3,6,7,12,13,15] For tapered limbs, contouring the cuff to match the conical shape of the limb has been shown to reduce limb occlusion pressure.[17] In a review of an earlier version of the wide cuff used in this study, a bloodless field was maintained in all 58 cases at a standardized 250 mm Hg cuff pressure at the thigh.[16] This is approximately 25% greater than the mean cuff pressure predicted by the results from the current study. In a clinical series, Pedowitz et al[17] obtained a fair or better bloodless field in 10 of 10 patients using a slightly narrower (12.0 cm versus 13.8 cm) contoured cuff at a limb occlusion pressure plus 50–75 mm Hg (mean cuff pressure, 197 mm Hg; range, 160–275 mm Hg; standard deviation, 37). The results of our clinical study with the wide cuff support the findings of Pedowiz et al[17] and additionally provide a direct comparison between modern, commercially available tourniquet cuffs.

The results of the current study suggest that use of the new automated plethysmographic limb occlusion pressure measurement system and a standard cuff can reduce average cuff pressures compared with typical practice. Using a wide contoured cuff allowed an additional reduction of average pressure. Limb occlusion pressure was not well correlated to systolic blood pressure, and systolic blood pressure alone does not seem to be a reliable indicator of optimum tourniquet pressure. The plethysmographic technique was effective and easy to use on most patients, generally requiring approximately 30 seconds to complete and automatically determining an optimal tourniquet pressure without requiring additional input from the user, a distinct advantage over previously reported methods. However, the number of patients on whom a good measurement could not be made indicates that refinements to increase sensitivity to weak distal pulses should be made. Until an automated plethysmograpic system similar to the one used in the current study is commercially available, the established Doppler stethoscope method of limb occlusion pressure measurement may be used to achieve similar results.

In view of these results and prior recommendations in the relevant clinical literature, we recommend applying and using tourniquet cuffs in the thigh region on adults as follows: (1) Select the widest cuff suitable for the selected limb location[1,3,6,7,15,17] and if possible use a contoured cuff able to match the taper of the thigh.[17] Ensure that the cuff is clean and in good working condition.[1] For example, check for excessive lint that may be fouling the hook and loop fasteners and that the cuff does not have permanent kinks or ridges on its inner surface; (2) If possible select a limb protection sleeve specifically designed for the selected cuff. If such a sleeve is not available, apply two layers of tubular stockinet or elastic bandage, sized such that it is stretched when applied to the limb at the cuff location and such that the compression applied by the stockinet or elastic bandage is less than venous pressure (approximately 20 mm Hg) and less than the pressure of a snugly applied cuff[22]; (3) Apply the tourniquet cuff snugly over the limb protection sleeve, and prevent fluids such as limb preparation solutions from collecting between the cuff or sleeve and the patient's skin[1]; (4) Using the applied cuff, measure the patient's limb occlusion pressure (using any validated method), and set the tourniquet pressure at limb occlusion pressure plus a safety margin: 40 mm Hg for limb occlusion pressure less than 130 mm Hg, 60 mm Hg for limb occlusion pressure of 131–190 mm Hg, or 80 mm Hg if the limb occlusion pressure is greater than 190 mm Hg[4,5,10,12,13,17,19]; (5) Exsanguinate by elastic bandage or elevation, as appropriate for the patient and procedure[1]; (6) Inflate the tourniquet cuff and monitor the tourniquet during use, as recommended by the manufacturer[1]; (7) In the event that arterial blood flow is observed past the tourniquet cuff, increase tourniquet pressure in 25 mm Hg increments until the blood flow stops[17]; (8) Minimize tourniquet time[1]; and (9) Immediately on deflation of the tourniquet, remove the cuff and sleeve from the limb.

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