

Pediatric Tourniquets: Analysis of Cuff and Limb Interface, Current Practice, and Guidelines for Use

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Summary: There are few clear guidelines on the proper use of tourniquets in pediatric surgery, in particular on how to set the tourniquet pressure, how to select the most appropriate cuff, and whether to use some type of soft padding beneath the cuff for limb protection. The authors could find only one published study specifically addressing pediatric cuff pressures, and no studies showing what types of cuff and/or padding create the smoothest skin surface under the cuff. Of 46 pediatric orthopaedic surgeons surveyed, 44 use a tourniquet 4.6 times per week on average and 2 have discontinued their use as a result of complications. To set cuff pressure, 13 of 44 use a standard value, 14 of 44 base pressure on age, extremity, and size, and 17 of 44 base cuff pressure on blood pressure. Thirty-four of 44 use skin protection under the cuff, but damage to the skin is common, accounting for 21 of the 67 reported complications. Nerve (15/67) and muscle (8/67) complications, related to both pressure and tourniquet time, were also reported. Using a mold-

ing and digital measurement technique, the authors compared the maximum wrinkle heights and the sums of all wrinkle heights in the skin surface under four different cuff/padding configurations. In a total of 44 trials on the upper arms and thighs of two healthy child volunteers, one type of pediatric cuff with a matching limb-protection sleeve designed and recommended by the manufacturer (Delfi) produced significantly fewer, less severe pinches and wrinkles in the skin surface than a second type of tourniquet cuff (Zimmer) with or without two layers of commonly available cast padding, and a third type (Kidde) with padding. With the second type of cuff, using cast padding reduced skin wrinkling compared to applying the same cuff on unprotected skin. In view of the survey, clinical literature, and results of this study, a guideline for use of pediatric tourniquets is proposed. **Key Words:** Guideline—Hazard—Injury—Pressure—Survey—Tourniquet.

High pressures on the tissues under or near a tourniquet cuff can cause injury (Fig. 1) (3,7–10). To help reduce skin surface damage under the cuff, some tourniquet cuff manufacturers provide stockinet limb-protection sleeves of various types (Smith & Nephew Richards, Memphis, TN; Delfi Medical, Vancouver, British Columbia, Canada), whereas others supply only tourniquet cuffs and make no specific recommendations about the use or nonuse of underlying padding for limb protection (Zimmer, Inc., Warsaw, IN; Walter Kidde Inc., Mebane, NC). One recommended practice guideline suggests that stockinet or cast padding can be used but also states that some tourniquet cuffs do not require padding and ultimately refers the clinician to the manufacturers' recommendations (1). There is currently no

quantitative evaluation of the severity of wrinkling and pinching of the skin under the cuff in the literature, so it is not clear what type of cuff/limb-protection combinations lead to even application of pressure to the skin and minimal chance of skin damage. There is also very little in the literature specifically addressing proper tourniquet use in pediatrics.

To determine the current clinical practice of tourniquet use in pediatrics and to identify the most common types of complications, we conducted a survey of U.S. and Canadian pediatric surgeons. We also developed a technique of making and analyzing an imprint of the cuff/skin interface to compare quantitatively wrinkling and pinching of the skin under various combinations of cuffs and padding materials. In this paper we present the results of our survey and the results from multiple trials of four commonly used cuff/padding configurations on two healthy child volunteers. Our hypothesis is that some types of cuffs and/or padding will cause substantially less wrinkling and pinching of the skin than others. As a corollary, we infer that this indicates a more even pressure distribution and reduced risk of skin and soft tissue damage.

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FIG. 1. Skin injury after typical cuff application over cast padding possibly related to cuff/skin interface and/or pressure: posterior aspect (60 minutes tourniquet time, infant clubfoot surgery).

METHODS

Survey

Current clinical practice was assessed by a two-page questionnaire designed by an attending pediatric orthopaedic surgeon, a resident, and a biomedical engineer and sent to recognized pediatric orthopaedic surgeons across North America. Fifty-two questionnaires were e-mailed to surgeons in the United States and forty questionnaires were mailed to surgeons in Canada.

Skin wrinkle/pinch measurement technique

To approximate the deformation of the skin surface in contact with the cuff or padding, we placed a layer of modeling clay sheet (Model Magic, Binney & Smith Canada, Lindsay, Ontario, Canada, extruded through rollers to a uniform 2.5 mm thickness and covered with a single layer of plastic film) on the limb of the subject. An experienced technician applied the padding (if used) and cuff, ensuring that the overlap of the cuff was positioned over the modeling clay sheet. Using a Zimmer A.T.S. 2000 tourniquet instrument, the cuff was inflated to 200 mm Hg for 1 minute, deflated, and removed. The

modeling clay sheet (now imprinted with the texture of the cuff or padding on the top surface and the skin texture on the underside) was removed, allowed to dry, and bonded skin side down to a flat plastic card using double-sided tape. The top surface (cuff/padding imprint) of the mounted mold was then digitized in a 5-mm (proximal-distal) by 0.20-mm circumferential grid on a coordinate measuring machine (Picza Pix-3; Roland Digital Group, Auckland, New Zealand). Figure 2A shows the resulting image of a typical mold. The resulting section profiles approximate the circumferential profile of the skin surface at 5-mm (proximal-distal) intervals under the cuff. An area of 95 mm (circumference) by 45 mm (proximal-distal, 10 sections spaced at 5-mm intervals) at midcuff, including the cuff overlap, was analyzed on all trials.

Definition of roughness or irregularities in the skin surface

Wrinkles in the skin surface were defined as a change in height of ≥ 1 mm with a slope of 0.25 (1-mm height change for every 4 mm of distance along the skin surface) or steeper, lying within a 10-mm circumferential length of skin surface (Fig. 2B). Wrinkles < 1 mm high were ignored. Pinching of the skin, where the skin was gathered by the cuff from a deep level up to a superficial peak and back down again within 20 mm, were counted as two wrinkles. The maximum wrinkle height and the sum of all wrinkles > 1 mm high found on each mold were compared. To confirm the precision of the digitizing process, a typical mold was digitized five times, resulting in standard deviation across the five repetitions of 0.03 mm (± 0.08) for maximum wrinkle height and 2.2 mm (± 6.0) for the sum of all wrinkle heights. Examples of typical pinch and wrinkle profiles are shown in Figure 3.

Study design

Ethical approval was granted by the University of British Columbia. The subjects tested are described in Table 1. Four different cuff/padding configurations (Table 2) either recommended by cuff manufacturers or commonly used (as indicated by the survey results) were chosen for comparison. Each configuration was tested using five repeated trials on the upper arms and one trial on the right leg of subject 1, and three trials on the upper

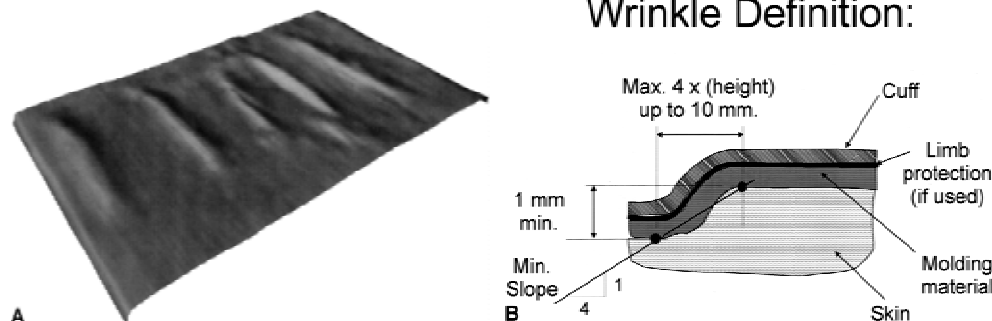


FIG. 2. Image of typical mold (A) and wrinkle definition parameters (B).

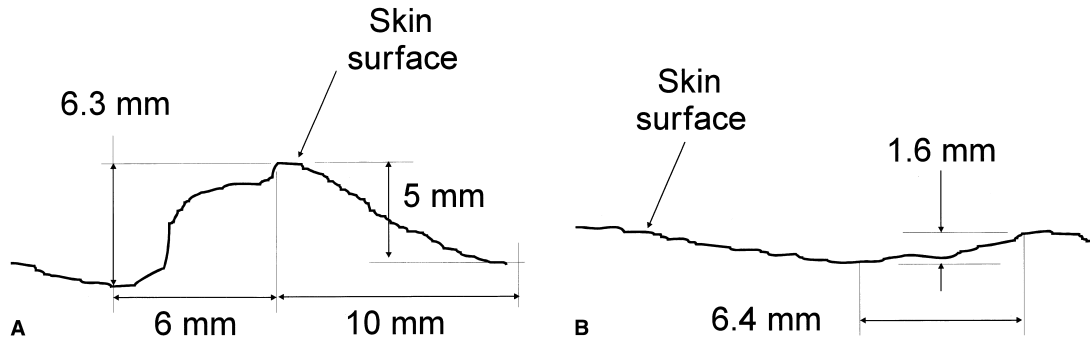


FIG. 3. Profile of a large pinch (A) vs. typical small wrinkle (B).

arms and one trial on each thigh of subject 2 for a total of 44 trials. Both subjects were healthy with normal skin and muscle tone, and both were comfortable with cuff application and the laboratory setting before testing began. To compare maximum wrinkle heights, rank sums were compared using the Friedman statistic and all possible pairs of configurations were compared using an SNK test (4). Wrinkle height sums were compared using the same method.

RESULTS

Survey results are shown in Table 3. The four common cuff/limb-protection configurations are compared in Figure 4.

DISCUSSION

Survey of tourniquet practices and complications

Rudolph et al. (10) surveyed 44 clinics in Europe concerning >75,000 procedures involving tourniquet use (adult and pediatric). Tissue damage was reported in 1.4% of lower limb and 0.4% of upper limb cases (usually reddening with blisters). Many cases involved fluids such as disinfectant flowing under the cuff, but in general the survey indicated that fluid leakage, excess pressure, excess duration of cuff use, or a combination of these factors could cause skin damage. Two cases of skin lesions were reported involving small children where disinfectants were not used, but sweat had accumulated under the cuff. Sixty-five percent of the clinics reported using cotton padding material, 20% other types of padding, and 15% no material under the cuff. Our survey results indicate that a similar proportion (13.6%) of pediatric clinics use no limb protection or padding and that skin damage is the most common injury, accounting for 21 of the 67 complications reported. Choudhary et al. (3) reported a case of friction burns on an adult patient's leg

as a result of the tourniquet cuff sliding distally off the padding material during the procedure. No fluids were found under the cuff in this case.

In the only recent published clinical study of pediatric tourniquet techniques, Lieberman et al. (6) found that when using limb occlusion pressure plus 50 mm Hg to set cuff pressure, adequate hemostasis may be achieved at lower pressures than those commonly used. Our survey showed that surgeons are evenly divided among using a preset standard pressure, basing pressure on age, extremity, and size, and basing cuff pressure on blood pressure. Of the surgeons referring to blood pressure, 71% use 100 mm Hg above systolic and 29% use two times systolic. Both methods lead to substantially higher cuff pressures than Lieberman et al.'s recommendations, and because 44 of the 67 (66%) reported complications were pressure-related (skin damage, nerve-related injuries, and muscle injury), a method based on limb occlusion pressure should be adopted to minimize cuff pressure (Appendix).

Tourniquets are often deflated during operations when there has been a prolonged period of inflation or when a bloodless operating field is no longer required. In our survey, the majority of surgeons (67.4%) indicated that they would leave the deflated tourniquet in place until the case was complete. However, one surgeon reported a bilateral lower extremity case in which the primary cuff remained inflated without indication while the second

TABLE 2. Cuff and limb protection configurations

Configuration	Description
Zimmer/unprotected	Zimmer 8" or 12" A.T.S. Reusable Cuff with no limb protection (no manufacturer recommendation; based on survey of use)
Zimmer/pad	Zimmer 8" or 12" A.T.S. Reusable Cuff with two layers of cast padding (no manufacturer recommendation; based on survey of use)
Kidde/pad	Kidde 12" or 18" Cuff with two layers of cast padding (no manufacturer recommendation; based on survey of use)
Delfi/sleeve	Delfi P2.25, P3.00, or P3.50 Pediatric Cuff with Delfi Limb Protection Sleeve (as recommended by manufacturer)

TABLE 1. Subjects

Subject	Description
1	5-year-old boy, 25 kg, 127 cm height, 190 mm arm and 330 mm thigh circumferences
2	7-year-old girl, 36 kg, 139 cm height, 240 mm arm and 400 mm thigh circumferences

TABLE 3. Survey results

Response rate U.S.		
E-mail response rate	33/52	63.5%
Canadian mail response rate	13/40	32.5%
Total response rate	46/92	50.0%
Two respondents no longer use tourniquets because of associated complications.		
Frequency of tourniquet use	204/44 = 4.6 per week (range 2–19/week)	
Age breakdown of patients with tourniquet use (yr)		
0–2		18.5%
3–5		18.8%
6–8		20.2%
9–12		19.8%
>12		22.8%
Type of tourniquet used		
Zimmer	36/54	66.7%
Other	7/54	13.0%
Don't know	11/54	20.4%
Ten surgeons gave two responses to this question.		
Use of underlying protective device for the skin		
Always	34/44	77.3%
Never	6/44	13.6%
Sometimes	4/44	9.1%
Is the tourniquet removed at time of deflation?		
Yes	14/43	32.6%
No	29/43	67.4%
Method of determining cuff pressure		
Standard preset pressure	13/44	29.5%
Based on age, extremity, and size	14/44	31.8%
Based on blood pressure	17/44	38.6%
100 mmHg over systolic BP	12/17	27.3% of total
Two times systolic BP	5/17	11.4% of total
Breakdown of reported complications (n = 67)		
Blood in surgical field	23/67	34.3%
Soft tissue blisters, burns, rash, contusions, abrasions	21/67	31.3%
Nerve-related injuries	15/67	22.4%
Muscle injuries	8/67	11.9%

limb was being operated on, leading to severe ischemic damage and eventual amputation of the primary leg. Complications may also occur if a snugly applied cuff occludes venous flow even when deflated. These risks can be eliminated by removing the cuff immediately after deflation.

Comparison of cuffs and padding materials

There is little discussion of pinching of the skin or local high- or low-pressure areas caused by wrinkles in the inflated cuff. Pedowitz et al. (8) qualitatively observed a difference in the limb shape and skin “ridges” (pinched areas) on cross-sectional computed tomography

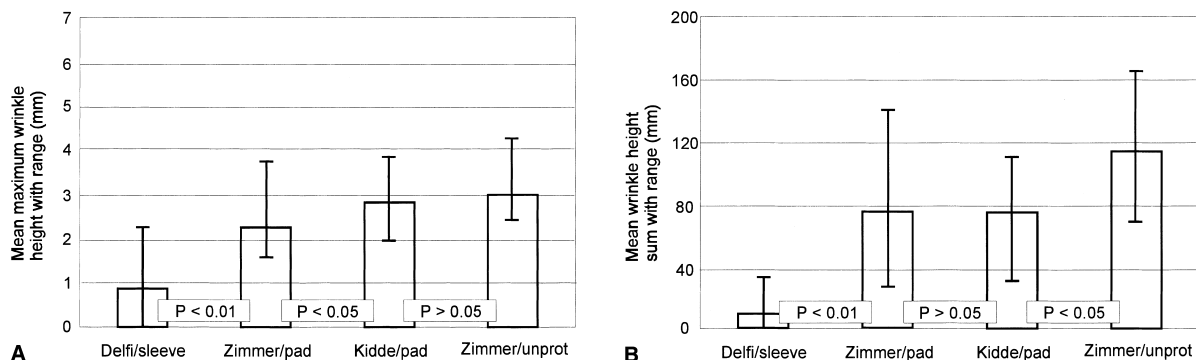


FIG. 4. **A:** Mean maximum wrinkle or pinch heights. **B:** Mean sums of wrinkle and pinch heights for common cuff or padding configurations (n = 11 trials of each group).

views of a rabbit hindlimb under two different cuffs. He noted similar ridges in magnetic resonance images of a human thigh under tourniquet pressure but did not analyze these differences in detail. In a brief note on technique, Harland and Lovell (5) observed that unprotected skin under a cuff can be damaged as a result of shearing stresses and that stockinet folded back over the cuff is effective as a padding material and in keeping the cuff in position.

In the current study, we introduce a quantitative method to compare the severity of wrinkling and pinching of the skin under the inflated cuff. Maximum wrinkle height represents the single most severe wrinkle or pinch found on a sample regardless of the number or height of the remaining wrinkles. The wrinkle height sums provide comparisons of both the severity and quantity of wrinkles and pinches >1 mm high.

Comparing four commonly used combinations of cuff and padding (Fig. 4), the Delfi cuff used with the matching Delfi stockinet sleeve produced significantly lower maximum wrinkle heights and lower wrinkle height sums than each of the other configurations ($P < 0.01$). In 5 of the 11 trials, the Delfi cuff/sleeve combination had no wrinkles or pinches >1 mm and produced pinches >2 mm high in only one trial (subject 2, right thigh, maximum height 2.3 mm). For the Zimmer cuff, cast padding reduced both maximum wrinkle height and wrinkle height sum ($P < 0.05$) compared to applying the same cuff over unprotected skin. The Zimmer/pad configuration also had a lower maximum wrinkle height than the Kidde cuff with padding ($P < 0.05$), but there was no difference in the wrinkle height sum because of the higher quantity of small (1–2 mm high) wrinkles found with the Zimmer/pad. For the Kidde cuff with padding, maximum wrinkle height was similar to the Zimmer cuff with no limb protection ($P > 0.05$), but the wrinkle height sum was lower ($P < 0.05$) because of the greater quantity of small wrinkles found with Zimmer/unprotected.

With cast padding and no limb protection, the most severe wrinkling and pinching usually occurred at the cuff overlap. The Delfi sleeve is designed to stretch a controlled amount when applied to the limb, applying light compression and in effect “artificially” improving the tone of the skin under the cuff and making the skin resistant to being gathered up into a pinch by the cuff, particularly at the cuff overlap. Although a standard tensor material (e.g., Esmarch bandage) can be wrapped around the limb to the same effect and is sometimes used alone as a tourniquet, the pressure applied to the limb is highly variable depending on operator technique. Biehl et al. (2) measured pressures under Esmarch bandages used as ankle tourniquets in multioperator tests of 3- and 4-inch-wide material wrapped three and four times. Standard deviations were 35 to 53 mm Hg, high enough to indicate that elastic material wrapped manually as limb protection could pose a risk of occluding venous flow (leading to venous congestion) or of applying potentially harmful pressures to the limb even after deflation of the cuff.

Wrinkles alone represent an abrupt step in the skin and

may indicate areas of high shear stresses, the most common example being at the cuff overlap. Pinches, treated in this study as two back-to-back wrinkles, may indicate a region where the cuff is not applying even pressure to the limb, and a vessel passing under a large pinch may require more cuff pressure for occlusion. Larger pinches (≥ 3 mm high) persisted with the Zimmer and Kidde cuffs even when cast padding was used.

Limitations

The mold material itself may affect pinching of the skin, and at this stage no attempt was made to measure differences in the absolute dimensions of irregularities in the skin surface between actual tourniquet use and the molds. A validation study using limb cross-section views (e.g., magnetic resonance imaging) could be done with adult volunteers, but we believe that this is not appropriate for child subjects, so the current method can be used as a comparison measure only. The comparisons are valid under the limitation that the two subjects represent typical pediatric patients. Ideally each cuff/padding configuration would be tested once on a wide variety of children representing the full pediatric age range. In the current study we included multiple trials on the upper arms and thighs of two subjects only, which reduces the effect of intersubject variability (as a result of differing limb sizes and soft tissue properties). This makes the test more likely to detect significant differences for a given number of trials, to the degree that the true intersubject variability in the pediatric population is substantial in relation to intrasubject variability. The detection of irregularities is sensitive to the height, slope, and maximum distance parameters chosen (Fig. 2B), and results will change with these parameters. The parameters were adjusted by reviewing each section of a variety of molds and confirming that all irregularities that would be subjectively identified on the mold as a wrinkle or pinch were recorded by the data processing routine. The chosen parameters were then used on all molds and each section was reviewed during processing.

In summary, there is a lack of clear guidelines and published studies referring to proper tourniquet use in pediatrics. Our survey results show that skin damage is one of the common complications of pediatric tourniquet use and that the use of limb protection under the cuff and techniques of cuff pressure selection are varied. The different methods of pressure selection commonly used may lead to higher pressure than necessary. Our comparative measurements of skin surface deformation under tourniquet cuffs showed that based on a total of 44 trials of four different cuff/padding configurations on the upper arms and thighs of two healthy pediatric subjects, the Delfi pediatric cuff used with the matching Delfi limb-protection sleeve significantly reduces the quantity and maximum height of skin wrinkles and pinches compared with all other configurations ($P < 0.01$). For the Zimmer cuff, using cast padding reduces the quantity and the maximum height of wrinkles and pinches versus applying the same cuff over unprotected skin ($P < 0.05$). Using a Kidde cuff over cast padding produced maxi-

mum pinch heights similar to the Zimmer cuff with no limb protection.

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Appendix: Proposed Guideline for Use of Pediatric Tourniquets

In view of the survey results, clinical literature, and results of this study, a guideline for use of pediatric tourniquets is proposed.

- Select the most proximal portion of the limb as the cuff location.
- Select the widest cuff suitable for the selected limb location and the surgical procedure.
- 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, sized such that it is slightly stretched when applied to the limb at the cuff location and such that the compression applied by the stockinet is less than venous pressure (~20 mm Hg) and less than the pressure of a snugly applied cuff.
- Apply the pediatric tourniquet cuff snugly over the limb-protection sleeve.
- Using the applied cuff, measure the patient's limb occlusion pressure and set the tourniquet pressure at that pressure plus a safety margin, normally 50 mm Hg for a normotensive pediatric patient having a normal limb.
- Exsanguinate by elastic bandage or elevation, as appropriate for the patient and procedure.

- Inflate the tourniquet cuff and monitor the tourniquet during use, as recommended by the manufacturer.
- If arterial blood flow is observed past the tourniquet cuff, increase tourniquet pressure in 25-mm Hg increments until blood flow stops.
- Minimize tourniquet time.
- Immediately on deflation of the tourniquet, remove the cuff and sleeve from the limb.

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