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The Safety and Effectiveness of an In-Depth Esmarch Tourniquet Technique in Achieving Target Pressures for Pediatric Upper Extremity Surgery

Kanchai Malungpaishrope, MD, Prapasiri Charoensri, MD, Piyabuth Kittithamvongs, MD, Navapong Anantavorasakul, MD, Chairoj Uerpairojkit, MD, Somsak Leechavengvongs, MD

Upper Extremity and Reconstructive Microsurgery Unit, Institute of Orthopaedics, Lerdsin General Hospital, Department of Orthopaedic Surgery, College of Medicine, Rangsit University, Bangkok, Thailand

Purpose: This study aimed to determine the appropriate number of turns required for an Esmarch tourniquet, using commonly sized Esmarch bandages, to achieve a pressure target of at least 150 mm Hg during pediatric upper extremity surgery.
Methods: Twenty participants who underwent upper extremity surgery were included in the study. Two surgeons used 2- and 3-inch-sized Esmarch bandages to apply an Esmarch tourniquet to each participant's arm. The pressure and number of turns were recorded from the second to fifth turns. The pressure was measured using a pressure sensor device.
Results: At the third turn of both the 2- and 3-inch-sized Esmarch bandages, a 150 mm Hg pressure was achieved in all participants. Intra-observer reliability resulted was "good"; however, inter-observer revealed "poor" reliability.
Conclusions: The Esmarch tourniquet is an effective and safe method for creating a bloodless operative field for upper extremity surgery in pediatric patients. The results of this present study suggested the application of three turns of the 2- and 3-inch-sized Esmarch bandages.

Keywords: Esmarch, pressure, tourniquet, upper extremity surgery, children

Pneumatic tourniquets are widely used in upper extremity surgeries. However, a child's limb has unique characteristics for which a traditional pneumatic tourniquet is not suitable, including the relatively small limb size that may leave no space for the application of a pneumatic tourniquet. Furthermore, acute tapering of the extremities often results in distal sliding of the tourniquet[1].The standard tourniquet pressure recommended for surgery in the upper extremities of children ranges from 150 to 250 mm Hg[2]. The use of different methods, such as skin protection techniques and the availability of various commercial pneumatic tourniquet systems may result in variations in the applied pressure, often leading to higher pressures than necessary[3,4]. Currently, no specific studies have investigated the appropriate size and number of turns of the Esmarch tourniquet required to achieve the desired pressure in the upper extremities of children during surgery. This study aimed to determine the appropriate number of turns for commonly sized Esmarch bandages to

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Correspondence to: Piyabuth Kittithamvongs, MD
Upper Extremity and Reconstructive Microsurgery Unit, Institute of Orthopaedics, Lerdsin General Hospital, Department of Orthopaedic Surgery, College of Medicine, Rangsit University, Bangkok, Thailand
E-mail: piyabuthortho@gmail.com

achieve a pressure target for upper extremity surgery in children.

METHODS

This study was approved by the Institutional Review Board of our hospital (LH611050). Informed consent was obtained from the parents of all participants. Participants aged between 3 months and 5 years who underwent upper extremity surgery were included in the study. The exclusion criteria were as follows: pathology at the site where the tourniquet would be applied; an underlying disease of abnormal blood circulation; or a coagulopathy. Two orthopedic surgeons (a highly-experienced, specialized pediatric hand surgeon and a non-specialized, fellowship-trained hand surgeon) performed the procedures of the application of 2- and 3-inch-sized Esmarch bandages.

The Esmarch Bandage Torniquet Technique

All the participants were placed in a supine position, and they received general anesthesia. The load cell of a pressure sensor device (FlexiForce™, standard model A201, Piezoresistive Force Sensor, Tekscan, USA) was placed on the medial aspect of the arm (Fig. 1). The two surgeons used two Esmarch bandages. One was used to exsanguinate the upper extremity, and the other was used as a tourniquet to control the pressure. The first Esmarch bandage (2-inch-sized) was applied starting from the distal to proximal aspect of the forearm (Fig. 2), and the second Esmarch bandage was applied proximal to the elbow. Subsequently, the surgeons applied 2- and 3-inch-sized Esmarch bandage tourniquets (VBM Medizintechnik GmbH, München, Germany) to each participant's arm (2-inch-sized Esmarch bandage first) by pulling the Esmarch bandage and stretched it to match the width of the upper arm in the coronal plane, to distribute a standardized pressure (Figs. 2, 3). An open straight clamp was applied before the last turn. The clamp was closed after the final turn (Fig. 4). The pressure measurements at the second to fifth turns were recorded. The 2-inch-sized Esmarch bandage was released. After a 3-min pause, the entire procedure was repeated, and the 3-inch-sized Esmarch bandage was used in the same manner. The two surgeons performed the applications of the 2- and 3-inch-sized Esmarch bandages, independently of each

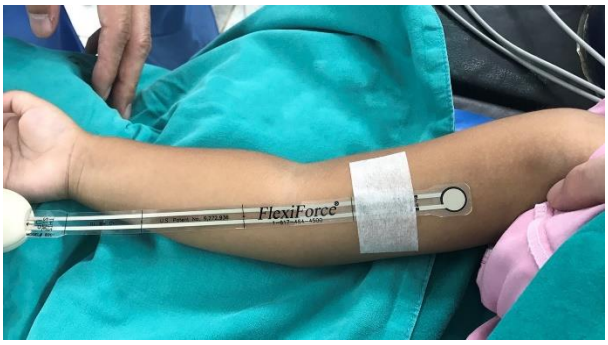

Fig. 1 The load cell is applied to the medial aspect of the arm.

Fig. 2 The surgeon gently pulls and stretches the Esmarch bandage to the width of the upper.

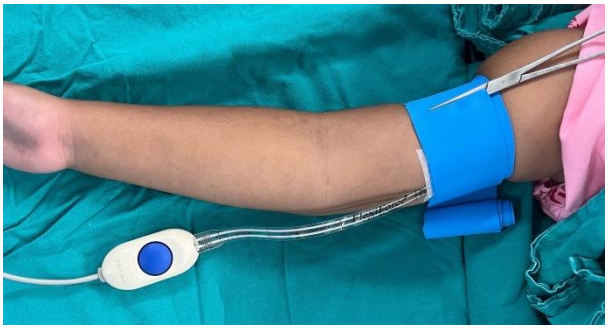

Fig. 3 The Esmarch bandage is applied.

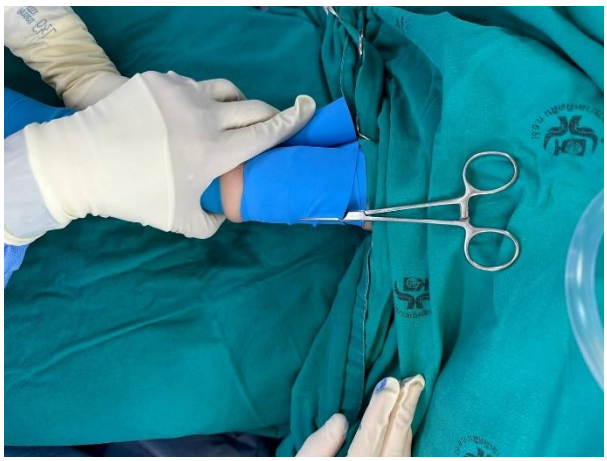

Fig. 4 A straight clamp is applied.

The average pressure of each turn of each sized bandage was measured and reported. A repeated measures analysis of variance (ANOVA) with post-hoc analysis was used to determine the difference between the measurements of pressure for each turn, with a p-value of less than 0.05 considered for significant significance. Intraclass correlation coefficient (ICC) was used for intra-observer (2-way random effects model; absolute agreement) and inter-observer (2-way mixed-effects model; absolute agreement) reliability.

RESULTS

Of the 20 participants that were included in the study, 9 were male and 11 were female patients. The average age of the participants was 29.2 months. For the 2-inch-sized Esmarch bandage, a pressure of 150 mm Hg was obtained at the third turn for both the surgeons in all participants (pediatric hand surgeon: mean= 185 mm Hg, SD= 13.4 mm Hg, range= 154–211 mm Hg; fellowship-trained hand surgeon: mean= 187 mm Hg, SD= 14.9 mm Hg, range= 152–213 mm Hg). Furthermore, for the 3-inch-sized Esmarch bandage, the target pressure of 150 mm Hg was obtained at the third turn for both the surgeons in all participants (pediatric hand surgeon: mean= 182 mm Hg, SD= 20 mm Hg, range= 136–216 mm Hg; fellowship-trained hand surgeon: mean= 190 mm Hg, SD= 21 mm Hg, range= 140–219 mm Hg; Table 1). Repeated measure ANOVA revealed a statistically significant difference in mostly all of the pressures between the 2- and 3-inch-sized Esmarch bandages for both surgeons. However, the pressures between the fourth and fifth turns of the 2-inch-sized Esmarch bandage that was applied by the pediatric hand surgeon (p= 0.06) and fellowship-trained hand surgeon (p= 0.44) did not reveal a statistically significant difference. Furthermore, no statistically significant differences were observed between the third and fourth turns (p= 0.82) and between the fourth and fifth turns (p= 0.32) for the 3-inch-sized Esmarch bandage that was applied by the fellowship-trained hand surgeon.

The intra-observer reliability revealed good agreement (ICC > 0.8) for both sizes, all turns, and both surgeons. In contrast, the inter-observer reliability revealed poor agreement (ICC < 0.5) for both sizes and all turns.

Table 1 Average pressures (mm Hg) of the 2- and 3-inch-sized Esmarch bandages; reported as mean (SD).

2-inch-sized Esmarch bandage	**Second Turn**	**Third Turn**	**Fourth Turn**	**Fifth Turn**
Pediatric hand surgeon	128 (18)	185 (13)	202 (24)	218 (26)
Fellowship-trained hand surgeon	138 (22)	187 (15)	205 (18)	215 (23)
3-inch-sized Esmarch bandage				
Pediatric hand surgeon	132 (20)	182 (20)	201 (24)	219 (28)
Fellowship-trained hand surgeon	133 (13)	190 (21)	199 (15)	212 (28)

DISCUSSION

Pneumatic tourniquets are commonly used in extremity surgeries by pediatric orthopedic surgeries. Previous studies have reported that a pressure approximately 100 mm Hg above the systolic blood pressure is considered to be the effective pressure for hemostasis[5]. However, most of these studies have been conducted on adults.

Currently, evidence for the proper use of tourniquets in children is limited. The standard tourniquet;t pressure used in children ranges from 150 to 250 mm Hg[2]. Lieberman et al. reported that the average pressure used in upper extremity surgeries in pediatric patients is 173.4 mm Hg (range= 155–190 mm Hg), and that the traditional pneumatic tourniquets do not fit the small-circumference extremities of pediatric patients less than 2-years-old[6]. Eidelman et al. reported that there is only a limited area on a pediatric patient's limb for the application of a tourniquet due to the small size of their extremities. In addition, acute tapering of a child's extremities often results in inadvertent distal sliding of the tourniquet[1]. The small size of the upper extremities probably results in the loss of tourniquet compression and causes blood leakage into the surgical field.

In 1993, Biehl et al. reported that the Esmarch tourniquet generated safe and reliable pressures during foot and ankle surgeries. The application of both the 3- and 4-inch-sized Esmarch bandages with three, circumferential, overlapping wraps has consistently resulted in a pressure that is within a safe range[7]. Regarding the use of an Esmarch tourniquet to achieve adequate hemostatsis during surgery, Abraham et al. recommended stretching the Esmarch bandage before wrapping each turn. The author observed that the pressure can increase at a rate of three to four times that of its initial pressure when the bandage is stretched after each wrap, rather than over the total length initially[8].

The present study demonstrated that three turns of the 2- and 3-inch-size Esmarch bandages generated the optimal pressure that could be consistently used as a tourniquet for upper extremity surgery in pediatric patients. Furthermore, we observed a good intra-observer reliability, although the inter-observer reliability was poor. This may attributed to the analysis method used (absolute agreement) and the variability among the surgeons. However, despite the lack of reliability between the surgeons, the effective pressure was obtained at the third turn for both sizes of the Esmarch bandages, for all the participants. At the third turn, the pressure did not exceed the recommended upper limit of 250 mm Hg in any of the participants.

A limitation of this study was its small sample size. Furthermore, the study revealed that a number of variable factors related to the pressure needs to be considered. The first is the difference between the physical pressures applied by individual surgeons. The second is the size and circumference of the pediatric patient's upper arm. The third is the brand and condition of the Esmarch bandage, which may affect its elasticity. A fourth factor is the variability in pressure that may result from the different technique used for stretching the bandage until the width of the bandage is equivalent to the width of the upper arm in the coronal plane. These variables affect the true value of the overall pressure achieved by individual surgeons. Further studies with larger sample sizes and involving more surgeons may be of benefit in refining further results.

CONCLUSIONS

The Esmarch tourniquet is an effective and safe procedure for creating a bloodless operative field for upper extremity surgery in pediatric patients. The results of this present study suggested the application of three turns of the 2- and 3-inch-sized Esmarch bandages to obtain an optimal pressure, which is considered to be between 150 and 250 mm Hg.

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