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Evidence for safe tourniquet use in 500 consecutive upper extremity procedures

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Abstract
Background Although pneumatic tourniquets are widely used in upper extremity surgery, further evidence is needed to support their safe use. Excessive pressure and prolonged ischemic time can cause soft-tissue injury. The purpose of this study was to determine the safety of tourniquet use in a yearlong, consecutive series of patients.
Methods A retrospective review of all patients who underwent upper extremity surgery by two board-certified hand surgeons over a 1-year period was performed. Demographic variables, comorbidities, and complications were noted along with tourniquet parameters, including application site, ischemic pressure, and time.
Results A total 505 patients were included in the study because a tourniquet was used during their operation. Patients ranged in age from 3 months to 90 years old (mean 40.1 years). More than half of the population was overweight (mean body mass index (BMI) 27.1), and 77.1 % of adults had at least one cardiac risk factor. No immediate or delayed tourniquet-related injuries were identified. The average operative time was 35.9 min, with an average tourniquet time of 33.1 min. Tourniquet inflation pressure of 250 or 225 mmHg was utilized in 78 and 21 % of adult patients, respectively; no patients had a pressure setting exceeding 275 mmHg.
Conclusion In this series of more than 500 operations, there were no immediate or delayed tourniquet-related events using parameters determined perioperatively by the attending surgeon. Tourniquet pressures of 250 mmHg or less in adult patients with less than 2 h of ischemic time appear to be safe, even in the elderly and patients with multiple medical comorbidities.

Keywords Tourniquet · Safety · Ischemia · Injury

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Introduction

Pneumatic tourniquets are widely used in upper extremity surgery. Their history is closely linked with limiting blood loss during amputation, and the present day function remains primarily the same—to maintain a bloodless surgical field. While the constricting device dates back more than 2,000 years to Roman "barbers," the term "tourniquet" is credited to Jean Louis Petit who presented his device in 1718. The first surgeon to describe use of the tourniquet beyond amputation dates to Lister in the 1860s. In 1873, Johann Friederich August von Esmarch described a flat rubber bandage used for exsanguination of a limb during tourniquet use. It was not until nearly a century later that Bruner first published reports evaluating the safety of tourniquets in surgery of the hand [3–5]. Since then, numerous publications, as well as proposed guidelines for safe tourniquet use, have studied the real and potential complications of prolonged ischemia [9, 10, 14, 16–18, 21, 22, 25, 27, 30, 31].

Tourniquet-related injury usually involves nerve and other soft tissues (e.g., skin, muscle, and vasculature) and is believed to be caused by the combined effects of direct compression by the tourniquet and ischemia distal to the inflated

cuff [13]. Studying these two factors more closely, Lundborg used animal models to demonstrate that irreversible nerve injury occurs after 8 h due to ischemia. Interestingly, similar histological changes are seen after only 2 to 4 h of tourniquet compression. This suggests that compression may be more important than ischemic time, at least in the pathogenesis of nerve injury [13]. The reported severity of tourniquet-related nerve injury ranges from mild paresthesias to full paralysis. Unfortunately, the actual contribution of tourniquet time to this process is not clear in the clinical setting, because tourniquet time has varied between 28 and 160 min in cases of reported paralysis [1, 2, 9, 13, 14, 16, 18, 23].

Muscular injury seems to be more influenced by ischemic time rather than direct compression pressure [15, 17, 20, 21, 27, 31]. The tourniquet causes tissue ischemia beneath and distal to the cuff, leading to metabolic changes that become more severe and difficult to reverse with sustained tourniquet inflation time. Studies have shown that intracellular creatine phosphate and ATP are completely depleted after 2 to 3 h of ischemia. This increases the time required for metabolic recovery after surgery and is the physiological basis for limiting continuous tourniquet time to between 2 and 3 h [20, 26]. Wilgis has written that after 2 h of tourniquet inflation, a minimum of 15 min is necessary to restore metabolic balance to an ischemic limb [31]. Finally, skin injury appears to occur more commonly from failure to secure padding between the cuff and skin interface, rather than tourniquet pressure or ischemia time [7, 11, 19].

The high frequency of tourniquet use and the potential morbidity associated with the local effects of tourniquets necessitates a careful and empirical evaluation of tourniquet safety in order to protect patients from injury as well as physicians from the pressures of an increasingly litigious climate. While appropriate padding is a simple maneuver that may prevent skin injury, the main variables involved in tourniquet safety—ischemic pressure and duration of ischemia—remain debated [11].

Numerous publications have studied real and potential complications of prolonged ischemia, and various authors have made suggestions for safe tourniquet use [9, 10, 14, 16–18, 21, 22, 25, 27, 30, 31]. A common practice of tourniquet application is to use a default pressure for most cases, only deviating from this value when operating on children or patients whose comorbidities stratify them in a higher-risk group for tourniquet injury. Some authors have suggested adding 50–100 mmHg above the systolic blood pressure [6]. More accurate and complex methods involving formulas for individualizing tourniquet pressures have been derived based on quantifiable measures of tourniquet occlusion pressure (i.e., the pressure necessary to cause hemostasis). However, the need to frequently perform complex calculations on a case-by-case basis makes these approaches cumbersome and unlikely to be widely accepted [12, 22, 28, 29]. A recent analysis by Fitzgibbons et al. reviewed different parameters recommended by various groups for safe tourniquet use and provided a consensus summary recommendation. This thorough review cites nearly a dozen animal studies and more than 20 human studies [8].

Currently, our institution does not have a standard protocol for the selection or maintenance of tourniquet size, inflation pressure, ischemia duration, or reperfusion intervals. The purpose of this investigation was to observe the frequency of tourniquet-related injuries and to suggest safe parameters for tourniquet use in the upper extremity based on a retrospective review.

Methods

Following approval by the Rhode Island Hospital Institutional Review Board, we collected medical records for all patients who underwent upper extremity surgery by two board-certified hand surgeons at our institution (SS, JK) in 2011. Although the project was completed in a retrospective review, interest in tourniquet safety was an a priori research consideration by the senior surgeons, and therefore, special consideration was given in the examination of tourniquet-related injuries. Demographic variables including age, gender, and race were collected, along with factors which might potentiate tourniquet-related adverse

Table 1 Demographics—no. (% of sample)

	Number	Percentage
Gender		
Male	290	49.8
Female	292	50.2
Age (years)		
0–10	54	9.3
11–17	60	10.3
18–34	108	18.6
35–49	92	15.8
50–65	172	29.6
Older than 65	96	16.5
Body mass index (BMI=kg/m^2)		
<18.5 (underweight)	33	5.7
18.5–24.9 (normal)	167	28.7
25–29.9 (overweight)	178	30.6
30–40 (obese)	123	21.1
Greater than 40 (morbidly obese)	21	3.6
Not available	60	10.3
Frequency of medical comorbidities		
Hypertension	142	24.4
Hyperlipidemia	114	19.6
Tobacco use	75	12.9
Diabetes	51	8.8
More than one cardiac risk factor	448	77.0

Table 2 Tourniquet pressure inflation pressure by age

Age	<200 mmHg (%)	200 mmHg (%)	225 mmHg (%)	250 mmHg (%)	>250 mmHg (%)	Average systolic blood pressure (mmHg)
0–10	13.21	*75.47*	9.43	1.89	0.00	108.6
11–17	0.00	3.33	*48.33*	*48.33*	0.00	114.1
Greater than 18	0.78	0.78	20.37	*77.55*	0.52	152.7

outcomes including body mass index (BMI) and medical comorbidities. A detailed chart review was performed for each patient, documenting hypertension, smoking history, diabetes, and nearly a dozen other conditions.

In addition, we collected details about previous operations, preoperative diagnosis, procedure performed, operative time, skin-prep solution, blood pressure, body temperature, location and condition of tourniquet site pre- and postoperatively, tourniquet inflation pressure, ischemic time, and reperfusion periods when applicable. Detailed, electronic perioperative nursing records allowed for accurate and reliable assessment of these variables including a thorough skin assessment. Complete data were available in the electronic medical and surgical records for all patients. Descriptive and inferential statistics were performed using Excel (Microsoft, 2013).

Results

A total of 582 patients underwent hand or upper extremity surgery during the study period. A tourniquet was used in 505 (86.8 %) patients in the cohort. These patients ranged in age from 3 months to 90 years (mean 40.1 years). Males and females were evenly represented (49.7 vs 50.3 %). More than half of the study sample was overweight or obese, with a mean BMI of 27.1 (median 26.3). The most common medical comorbidities included hypertension (24.4 %), hyperlipidemia (19.6 %), and diabetes mellitus (8.8 %). More than three quarters of patients (77.1 %) had at least one cardiac risk factor including hypertension, hyperlipidemia, diabetes, tobacco use, coronary artery disease, or prior myocardial infarction (Table 1).

The average operative time was 35.9 min (range 6–257 min). Tourniquet time averaged 33.1 min (range 4–210 min). Only seven cases exceed 2 h of ischemic time, and only one tourniquet application lasted longer than 134 min. In this case, with a total of 210 min of tourniquet use, a 21-min reperfusion period was used after 120 min. No intraoperative bleeding events, venous ooze, tourniquet malfunction, or other complications were noted in the series.

A tourniquet inflation pressure of 250 mmHg was applied to 71 % of adult patients, 25 % had 225 mmHg, and the remaining 4 % had varying values depending on surgeon preference (maximum 275 mmHg). The average systolic blood pressure measured preoperatively was 143.5 mmHg, and the average cuff pressure above systolic pressure was 112.1 mmHg. Pediatric patients were divided into two age groups; those older than 10 years were more consistently treated with adult pressures either 225 mmHg (46.7 %) or 250 mmHg (41.2 %). In ages 1–10 years old (N=65), the most commonly used pressure was 200 mmHg (77.2 %) (Table 2).

Most adults were fitted with an 18-in. cuff (93.0 %). Obese patients were more likely to be fitted with a 24-in. cuff (average BMI 26.9 vs 31.1, respectively; $p<0.05$). All adult cuffs were 4 in. wide. Pediatric cuffs were fitted based on the child's size, though a 12- or an 18-in. cuff worked for all patients studied (Table 3).

Review of both the intraoperative and postoperative records did not reveal any tourniquet-related complications or adverse events (i.e., intraoperative bleeding, skin tears or chemical burns, compartment syndrome, nerve palsy, etc.). Documentation for each patient visit was reviewed. All patients had at least one follow-up examination.

Discussion

Tourniquet-related injury is a potentially avoidable complication of hand surgery that may result from improper skin protection, excessive tourniquet inflation pressure, or prolonged ischemic time. Numerous studies have attempted

Table 3 Tourniquet cuff size by BMI and age

	12 in. or smaller (%)	18 in. (%)	24 in. or larger (%)
Body mass index (BMI=kg/m^2)			
<18.5 (underweight)	*64.29*	35.71	0.00
18.5–24.9 (normal)	9.63	*86.67*	3.70
25–29.9 (overweight)	2.68	*90.60*	6.71
30–40 (obese)	1.79	*87.50*	10.71
Greater than 40 (morbidly obese)	0.00	*85.71*	14.29
Age (years)			
0–10	*96.29*	3.70[a]	0
11–17	13.56	*81.36*	5.00[b]
Greater than 18	1.08	*91.67*	7.26

[a] These two children with an 18-in. cuff were older (average age 9.5 years) and heavier (BMI 27.2) for this subgroup

[b] These three adolescents with a cuff larger than 18 in. (5.0 %) were older for the subgroup (average age 16.7 years) and much heavier (average BMI 36.1)

to optimize these variables, resulting in discordant recommendations from different groups. Although primarily based from lower extremity tourniquet literature, the extensive review article by Fitzgibbons et al. recommended using a tourniquet pressure of less than 250 mmHg for less than 150 min in the upper extremity [8]. We have found that these guidelines were safe in our series of patients, with only slight modifications including occasional pressures as high as 275 mmHg in adults and pressures generally less than 225 mmHg for pediatric patients younger than 10 years.

Drawing from this series, it is safe and effective to use tourniquet inflation pressures of approximately 100 mmHg above systolic blood pressure for up to 2 h. In both adult and pediatric patients, a reperfusion period of 15 min was used in the longest cases, but ischemic periods slightly longer than 2 h did not demonstrate increased complications.

With respect to cuff size, an 18-in. cuff was adequate for nearly all adult patients (93 %). Not surprisingly, patients in which larger cuffs were used (24 in. or greater) were significantly more likely to be obese. There have been studies demonstrating the merits of both narrow and wide cuffs; however, no studies have shown a clinical benefit regarding neurologic or functional outcomes with the use of a particular tourniquet design [8]. The cuff width in this current series was 4 in. in all cases, and therefore, no conclusions can be drawn regarding the safety of other cuff widths. Tourniquet location did not appear to be an issue, in agreement with previous studies; however, most of our tourniquets were placed on the upper arm as opposed to the forearm [6].

This approach employing a one-size-fits-all tourniquet selection for a diverse patient population and equally wide range of procedures had no tourniquet-related complications. While this approach was not studied as a "protocol" given the retrospective nature of the study, the results are still useful in finding no adverse events. The parameters for tourniquet use set forth in this investigation are similar to those proposed by an earlier review article on safe tourniquet use from one of the senior authors (EA), and this present study demonstrates safety of these prior recommendations [8].

Importantly, this series of patients included elderly and obese patients as well as those with cardiovascular comorbidities—all of which are known risk factors for tourniquet-related injuries [11]. More than half of this study population was either overweight or obese. As demonstrated by efficacy of hemostasis, the hypothesis that obese individuals may have decreased transmission of tourniquet pressure due to more conically shaped arms proved irrelevant at the recommended pressure of 250 mmHg, even for 21 morbidly obese individuals (highest BMI 62) [11]. Patients within the normal range for BMI did not suffer any injuries despite previous recommendations not to exceed 200 mmHg for average-sized individuals [29]. Elderly patients, who are at higher risk of skin injury due to increased susceptibility to sheer forces secondary to age-related thinning of the dermal-epidermal junction also did not experience tourniquet-related complications. Finally, patients with cardiovascular risk factors for atherosclerosis did not experience vessel thrombosis or any other vascular insult [24].

This study is limited by the retrospective nature of the review and a moderate sample size. As a result of the observational dataset, the average operative time is relatively short. A similar series of patients with longer mean operative times may have resulted in more complications. Additionally, it is feasible that patients may not have reported a transitory rash or a minor skin tear, not documented by the clinicians. Likewise, a larger dataset may be necessary to capture more serious, but rare, tourniquet-related complications. Nonetheless, the described practice patterns of the two surgeons in this study yielded no complications over a 1-year study period and provides data to support safety, in contrast to numerous case reports that describe only a rare complication. In order to more effectively test the hypothesis that the parameters described do in fact limit or prevent adverse events, a larger prospective observational study or a longer duration of retrospective review would be necessary. However, the sample size would need to increase substantially to identify risk factors given the exceedingly low rates found in this study.

Despite the limitations of this retrospective review, the safety and efficacy of tourniquet use are ostensibly demonstrated, although they are not proven. The sample size is moderate, and the patients are diverse in age and comorbidities. These data provide much needed support for the safe use of tourniquets in an increasingly litigious area of hand surgery. Further study is certainly needed as other authors have reported higher complication rates. However, this investigation demonstrates no tourniquet-related events during a yearlong study period using previously published recommendations [8]. Use of the pneumatic tourniquet significantly improves the experience of operating in the upper extremity, and the parameters previously published from our institution now have some empirical support from this series of patients.

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Conflict of interest Brian C. Drolet declares that he has no conflict of interest.
Zachary Okhah declares that he has no conflict of interest.
Benjamin Z. Phillips declares that he has no conflict of interest.
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Edward Akelman declares that he has no conflict of interest.
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