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Original Article

Relationship between Tourniquet Pressure and a Cross-Section Area of Superficial Vein of Forearm

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This study investigated the appropriate tourniquet pressure (TP) and duration of tourniquet application for venipuncture by calculating the venous cross-section (VCS) area on ultrasonography. Twenty healthy volunteers without cardiovascular risk factors were enrolled in this study. A target vein (either a cephalic or median cubital vein) was selected on ultrasonography. The pneumatic tourniquet was inflated using a rapid cuff inflator system at setting pressure for 120 sec. TP strength was varied from 20 mmHg to 100 mmHg, in 20 mmHg increments. The order of TP was randomized. Comparisons among more than 3 groups were performed by one-way repeated-measures ANOVA and the Bonferroni method. The VCS area increased rapidly until 10 sec after tourniquet inflation. The VCS area then increased gradually until 30 sec after tourniquet inflation. After that, the VCS area did not increase remarkably. The VCS area increased with TP strength up to 80 mmHg, but the VCS area at TP 100 mmHg decreased to less than that at TP 40 mmHg. Based on these results, we recommend a tourniquet pressure of 60 mmHg, and duration of tourniquet application is 30 to 60 sec for venipuncture.

Key words: venipuncture, tourniquet pressure, tourniquet duration, venous cross-section area, ultrasonography

Venipuncture is a frequently used medical skill in clinical settings. When nurses or clinical technicians perform venipuncture to the forearm, a tourniquet is applied to the upper arm in order to dilate the target vein. However, exact way of tourniquet application is not indicated [1-5]. The literature indicates only the tourniquet application site, 5 to 10 cm proximal to the cubital fossa [1-3]; the tourniquet application duration, less than 60 sec, because prolonged application of a tourniquet induces venous fragility and influences laboratory data [1-3, 6-9]; and tourniquet application strength, set higher than venous pressure and lower than arterial pressure [2-5, 10]. However, the literature does not show how fast the vein dilates or whether 60 sec after tourniquet application is sufficient for full vein dilatation, and the evidence of appropriate tourniquet pressure (TP) for venipuncture. In the United States, a publication called Procedures for the Collection of Diagnostic Blood Specimens by Venipuncture; Approved Standard Sixth Edition (CLSI document H3-A6; Clinical and Laboratory Standards Institute. 2007) [1] describes how to apply a tourniquet: "Blood pressure cuff should be inflated to 40 mmHg. Do not use

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higher pressures, as it may impair arterial blood flow to the extremity." However, the document does not provide evidence to support those recommendations. Although TP is an important factor in venipuncture or intravenous catheterization, there are no published reports indicating the appropriate TP or how to apply a tourniquet with appropriate pressure. Therefore, the strength of tourniquet application is estimated empirically by individual medical workers. Recently, Kato and Mori reported that the appropriate TP for venipuncture ranges from 70-95 mmHg with a gum-tube tourniquet [11]; the same authors also reported that most nurses apply a tourniquet with too much pressure [12]. However, they evaluated venous over-swelling by palpation, and the tourniquet application duration was only 60 sec. Therefore, it is necessary to determine in detail how venous dilatation changes with both TP and tourniquet application time.

This study investigated the influence of TP on venodilatation in order to determine the appropriate TP and duration of tourniquet application for venodilatation by ultrasonography.

Materials and Methods

Subjects. Twenty healthy volunteers without cardiovascular risk factors were enrolled. All subjects refrained from alcohol for at least 3 h before the experiment.

Equipments. The Rapid Cuff Inflator E-20 system (Hokanson, Bellevue, WA, USA) with an 11 cm width pneumatic tourniquet: this device can rapidly (within 0.3 sec) inflate a pneumatic tourniquet to a preset pressure and maintain that pressure for a long period. This cuff pressure can be accurately preset within a range of 0 to 300 mmHg in 1 mmHg increments.

An ultrasound system (Prosound2, ALOKA, Tokyo, Japan) with a 7.5 MHz linear scan probe was used to calculate the venous cross-section (VCS) area.

Video capture software (GV-MDVD3, I-O DATA, Kanazawa, Japan) was used to download the ultrasound images to a computer.

Measures. The study was performed in a quiet and temperature-controlled room (25 ± 1℃). The subjects lay on a bed in a comfortable supine position. A pneumatic tourniquet was applied around the upper arm, about 5 cm proximal from the cubital fossa. Measurements were obtained after a resting period of 10 min. A target vein (either a cephalic or median cubital vein) was decided by ultrasonography. After applying a sufficient amount of ultrasonic transmission gel on the skin of the target area, the probe was placed on the transmission gel with minimal pressure (Fig. 1). Ultrasound images of the target vein were continuously recorded by a computer. The pneumatic tourniquet was then inflated with the rapid cuff inflator system at setting pressure for 120 sec. TP strength varied from 20 mmHg to 100 mmHg, in 20 mmHg increments. The order of TP strength was randomized, and the inflation intervals were 5 min after deflation. Immediately after TP deflation, the subjects were asked how they felt about the tightness of the tourniquet. Subjective sensations of tightening were defined as "not tight", "a little tight", "tight", "very tight", or "painfully tight".

Data analysis. Ultrasound video movies were stored in a personal computer using video capture. The VCS area was calculated manually from the maximum and minimum axes of the VCS on an ultrasound image; an image was captured every 10 sec for 120 sec (Fig. 2). The expansion ratio (ratio) was estimated as the VCS area after tourniquet inflation / the VCS area before tourniquet inflation.

Statistical analysis. Data were analyzed using SPSS 19 (IBM SPSS Advanced Statistics, IBM, Tokyo, Japan). Data were expressed as the mean ± standard deviation (S.D.). Comparisons of the VCS area between 30 and 60 sec or 60 and 120 sec after

Fig. 1 Positioning of forearm in a fixation device. The ultrasound probe is fixed in a stand after optimal positioning for VCS of the forearm.

tourniquet inflation at the same TP were made using the paired *t*-test with the Bonferroni correction, and comparisons of the VCS area among TPs at the same number of sec after tourniquet inflation were performed using one-way repeated-measures ANOVA and the Bonferroni method. Furthermore, comparisons of the VCS area between TP 40 mmHg and TP 60 mmHg at the same number of sec after tourniquet inflation were performed using the paired *t*-test. $P < 0.05$ was considered to indicate statistical significance.

Ethics. All healthy volunteers gave written informed consent before participating in the study. The study was approved by the ethics committee of Okayama Prefectural University.

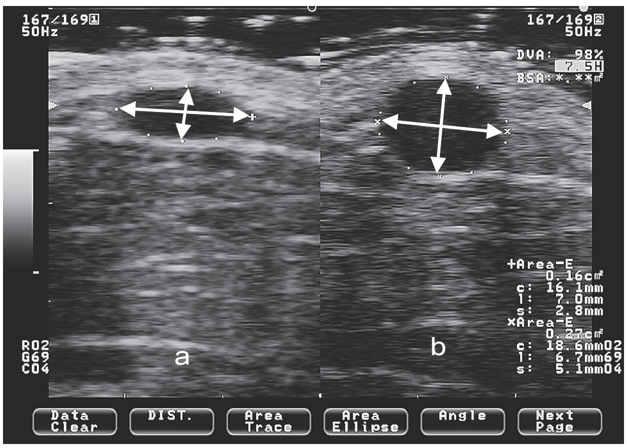

Fig. 2 A subject's ultrasound image (B-mode picture) of the median cubital vein, before (a) and after (b) tourniquet application at 60 mmHg for 60 sec.

Results

Twenty healthy volunteers, 5 men and 15 women, participated in this study. The mean subject age was 29.1 ± 12.9 (range: 18–63) years, systolic blood pressure was 112 ± 13.0 (range: 92–132) mmHg, and diastolic blood pressure was 68 ± 9.5 (range: 50–90) mmHg. In all TPs, the VCS shape changed from oval to circle (Fig. 2) and the VCS area increased rapidly until 10 sec after tourniquet inflation (Fig. 3). The VCS area increased gradually until 30 sec after tourniquet inflation. Thereafter, the VCS area did not

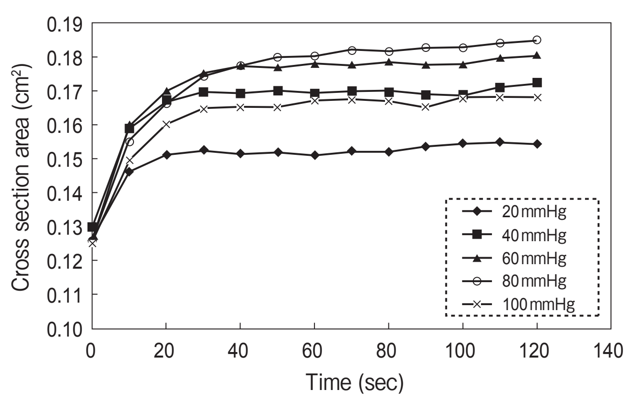

Fig. 3 Time course of VCS area at different TP.

Table 1 The effects of TP and tourniquet application time on VCS area (cm^2) and expansion ratio

Tourniquet pressure	Before	After 30 sec		After 60 sec		After 120 sec	
	VCS area	VCS area	Ratio	VCS area	Ratio	VCS area	Ratio
20 mmHg	0.126 ± 0.061	$0.153 \pm 0.066^{\$}$	1.25	$0.151 \pm 0.067^{\#}$	1.23	$0.154 \pm 0.070^{\#}$	1.25
40 mmHg	0.130 ± 0.060	0.170 ± 0.070	1.36	0.169 ± 0.068	1.36	0.173 ± 0.069	1.39
				&	*		
60 mmHg	0.126 ± 0.061	0.175 ± 0.072	1.46	0.178 ± 0.071	1.49	0.181 ± 0.072	1.52
80 mmHg	0.126 ± 0.064	0.174 ± 0.075	1.46	0.180 ± 0.074	1.52	0.185 ± 0.075	1.56
			*		*		
100 mmHg	0.125 ± 0.063	0.165 ± 0.077	1.35	0.167 ± 0.074	1.39	0.168 ± 0.075	1.40

Mean ± SD. $^{\$}p < 0.01$ compared with TP 40, 60, and 80 mmHg at 30 sec after tourniquet application. $^{\#}p < 0.01$ compared with TP 40, 60, 80, and 100 mmHg at 60 or 120 sec after tourniquet application. (One-way repeated-measures ANOVA).
$^{*}p < 0.05$ by paired *t*-test with Bonferroni correction. $^{\&}p < 0.05$ by paired *t*-test.

change remarkably, except at TP 80 mmHg. At only TP 80 mmHg, the VCS area increased slowly until 120 sec. The VCS area increased according to the TP strength up to 80 mmHg, but at TP 100 mmHg, it decreased to less than that at TP 40 mmHg. Table 1 shows the VCS area and expansion ratio before and at 30, 60, and 120 sec after tourniquet inflation. The VCS area increased slightly according to the time after tourniquet inflation. However, the increase in the VCS area was not marked except at TP 40 and TP 80 mmHg. At TP 40 mmHg, the VCS area after 60 sec was less than that at 120 sec. At TP 80 mmHg, the VCS area after 30 sec was less than at 60 sec, and that after 60 sec was less than at 120 sec. These differences in the VCS area were very small (2.4–3.4%). As mentioned above, the VCS area increased according to the TP strength up to 80 mmHg, but at TP 100 mmHg, the VCS area decreased. In a comparison by one-way repeated-measures ANOVA of the difference in the VCS area between TPs at the same number of sec after tourniquet inflation, only the VCS area at TP 20 mmHg was significantly smaller than that at the other TPs after 30, 60, and 120 sec, except at 100 mmHg at 30 sec. However, the paired *t*-test revealed that the VCS area was significantly smaller at TP 40 mmHg than at TP 60 mmHg at 60 sec after tourniquet inflation. The subjective sensation of tightening increased with pressure increase, and felt very tight at more than TP 80 mmHg (Fig. 4). Among all subjects examined, no one complained that it felt "painfully tight".

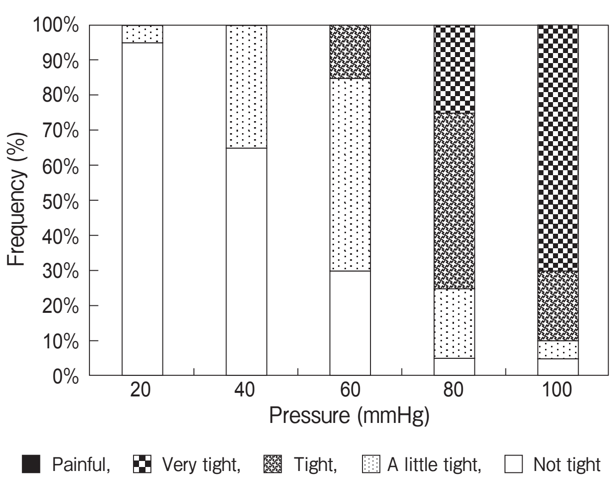

Fig. 4 Relationship between TP and subjective tightening feeling.

Discussion

One of the main findings of this study is that the VCS area increased rapidly within 10 sec after tourniquet inflation, and almost reached the maximum at 30 sec for all TPs. After 30 sec, the VCS area increased slightly. As indicated above, the literature recommends that venipuncture should be performed certainly and quickly, within 60 sec after tourniquet application, because prolonged application of the tourniquet would influence laboratory data [1, 2, 7–10, 13]. It is thought that dilation of the VCS area eases venipuncture; the present results support the validity of the 60 sec criterion, because 60-sec application of the tourniquet is sufficient for the VCS area increase, and a longer application of the tourniquet increases the VCS area only slightly. In the case of intravenous infusion, there is no concern regarding changes in laboratory data, but prolonged application of the tourniquet may cause discomfort and pain. Therefore, we recommend that the appropriate tourniquet application time for venipuncture is 30 to 60 sec.

Another finding is that the VCS area 60 sec after tourniquet application was significantly smaller at TP 20 mmHg than at the other TPs. This finding indicates that TP 20 mmHg is too low to facilitate venipuncture. As indicated previously, the CLSI document H3-A6 recommends TP 40 mmHg [1]. However, the VCS area at TP 40 mmHg tended to be smaller than that at either TP 60 or 80 mmHg. Furthermore, the paired *t*-test showed that the VCS area was smaller at TP 40 mmHg than at TP 60 mmHg at 60 sec after tourniquet inflation. Hence, TP 40 mmHg is sufficient for subjects in whom venodilatation is easily detected. However, subjects in whom venodilatation is not easily detected need a higher TP, such as 60 or 80 mmHg. The VCS areas at TP 60 mmHg and TP 80 mmHg do not differ significantly, but subjective sensation of tightening showed that TP 80 mmHg felt worse than TP 60 mmHg. Therefore, we recommend that TP 60 mmHg is appropriate for most subjects. The reason why the VCS area was smaller at TP 100 mmHg than at TP 60 or 80 mmHg is thought to be that 100 mmHg is nearly systolic blood pressure, and therefore peripheral blood flow will be impaired. Thus, TP more than 80 mmHg should not be used for venipuncture.

Recently, Kato and Mori reported that the appropriate TP for venipuncture ranges between 70 and

95 mmHg using a gum-tube tourniquet and from 45–90 mmHg using an elastic belt tourniquet [11]. On the contrary, this study showed that TP more than 80 mmHg is too high. The reason for this discrepancy is thought to be the difference in tourniquet widths between tourniquets: gum-tube, 8 mm; elastic belt, 2.5 cm; and the tourniquet used in this study, 11 cm. Moore *et al.* [14] and Crenshaw *et al.* [15] reported that wide tourniquets eliminate blood flow at lower pressure, because tourniquet pressure was attenuated in deep tissue when a narrow tourniquet was applied [16]. The effectiveness of the transmission of pressure on deep tissue using an 8-cm cuff is only about 64%, compared with more than 95% using 12 and 18-cm cuffs [15]. Based on our results, we recommend a venous cuff pressure of 60 mmHg as the standard because venodilatation seems to be greater at 60 mmHg than at 40 mmHg, and 60 mmHg was found to be less painful than 80 mmHg. Also, when a wide tourniquet such as the cuff of a sphygmomanometer is used, the appropriate tourniquet application duration ranges from 30 to 60 sec.

A limitation of this study is that all of the subjects were normotensive and healthy adults. If the subjects had included children, aged, hypertensive, or hypotensive patients, the appropriate TP may have been somewhat different.

In clinical settings, more than 70% of Japanese nurses applied the tourniquet with high pressure, over 100 mmHg [12]. The reason nurses did not apply a tourniquet appropriately is thought to be that they do not realize how tightly they are applying the tourniquet or how to apply it with appropriate strength. Therefore, it is necessary to develop a tourniquet with markers to guide its appropriate application pressure.

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