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SHORT COMMUNICATION

Transcutaneous pressure at which the internal jugular vein is collapsed on ultrasonic imaging predicts easiness of the venous puncture

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Abstract Even though we use ultrasound guidance for central venous puncture, we sometimes experience difficulties. We infer that in such cases the vein is collapsed and that the transcutaneous ultrasound probe pressure at which the vein is collapsed (P_{tc}) may predict the easiness of the venous puncture. We measured P_{tc} and the diameter of the internal jugular vein in 47 adult patients in our ICU. After successful puncture, we also measured venous pressure (P_v). The patients were divided into two groups based on the number of puncture attempts: ≥3 attempts constituted the "difficult group" and <3 attempts was considered the "easy group:" 33 patients were in the easy group and 14 patients were in the difficult group. The easy group showed significantly higher P_{tc} value (9.3 ± 3.8 vs. 3.5 ± 0.9 cmH$_2$O, $P < 0.0001$) and larger vertical diameter (9.2 ± 3.1 vs. 6.8 ± 2.2 mm, $P = 0.013$) than the difficult group. We observed a clear border between the minimum P_{tc} in the easy group (6 cmH$_2$O) and the maximum value in the difficult group (5 cmH$_2$O). In conclusion, venous collapsibility and vertical diameter determine difficulty in performing venous puncture.

Keywords Central venous catheterization · Ultrasound · Intensive care · Venous pressure

Recently, ultrasound (US) guidance is strongly recommended for safer insertion of a central venous catheter (CVC) [1–7]. However, the use of US during CVC insertion remains limited [8]. Real-time US especially is strongly recommended, but the lack of availability of US and the time delay to obtain US sometimes prevent the procedures from being carried out [9]. Furthermore, Bailey et al. [9] reported that 67% of cardiac anesthetists did not use US, which showed that US might not be considered indispensable by experienced physicians. Also, in our hospital, few doctors use real-time US guidance even if it is stated to be important. However, for physicians in training, CVC insertion is sometimes difficult, so we have been seeking a simple and reliable US guidance method to insert a CVC.

We routinely perform pre-puncture US screening of anatomical profiles of the vein. This method has been reported to be superior to the classical landmark method but to be inferior to the real-time US guidance method [10, 11]. We aimed to enhance the reliability of the pre-puncture screening method for young physicians so they can perform CVC insertion on their own.

From observation of real-time US during CVC insertion, trainees failed venous puncture when the vein was easily collapsed by slight transcutaneous pressure of the US probe. We infer that the collapse of the vein may result in failure of puncture and that the transcutaneous probe pressure at which the vein is collapsed (P_{tc}) may correlate with the difficulty. P_{tc} is noninvasively measurable by using US before the puncture. If the value of P_{tc} indicates difficulty, we could increase P_{tc} by infusion or by patient positioning before the catheterization. In this study, we examined the correlation of P_{tc} values with trials of the venous puncture for CVC insertion by a young doctor.

We set two roles for this study as follows: "study-examiners," who acquired data, and "an insertion performer," who catheterized the CVC. The study-examiners

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were well-experienced intensive care unit (ICU) doctors with more than 10 years in critical care careers. The insertion performer, a 3-year-career ICU trainee, was well trained to observe venous profiles by US and had experienced almost ten CVC insertions at the beginning of this study. This study was performed as a part of CVC insertion training, and the cases in which the study-examiner intervened were excluded from this study. All the patients who underwent CVC treatment exclusively by him were examined. We orally informed our patients of noninvasive measurement of P_{tc} and obtained written informed consent for CVC catheterization.

Before CVC insertion, we, the study-examiners, observed the anatomical profiles (localization and diameters) of the internal jugular vein (IJV) and measured P_{tc} by US (LOGIQ 400 HD and LA39 linear probe, 6.0–13.0 MHz; GE Medical Systems, Japan). Because no suitable device to obtain P_{tc} is commercially available, we used a homemade device. The pressure device placed between the probe and the skin should be ultrasonically transmissive, so the device consists of a water-filled, soft, thin plastic bag equipped with a manometer (Fig. 1). When the increased probe pressure occluded the IJV, we defined the pressure as P_{tc}. We verified that the probe did not directly touch the skin surface under the plastic bag when we measured P_{tc}. Preliminarily, we tested reproducibility of the homemade device in comparison with a clinical sphygmomanometer (no. 605P YAMASU; Kenzmedico, Japan). We placed the water-filled bag on the sphygmomanometer cuff, which was moderately inflated to a pressure of 0 mmHg, and applied random pressure on the water bag. We confirmed that the values simultaneously measured by the device and the sphygmomanometer were identical at any pressure from 0 to 30 mmHg.

We measured P_{tc} value and diameters at the apex of the angle formed between the two heads of the sternocleidomastoid muscle. After that, catheterization by the insertion performer, who was blinded to the measured P_{tc} value, was ordered. After pre-puncture US screening, he punctured the IJV by an 18 G needle (Arrow International). The number of his puncture attempts until successful catheterization was compared with the P_{tc} value. After the plastic cannula

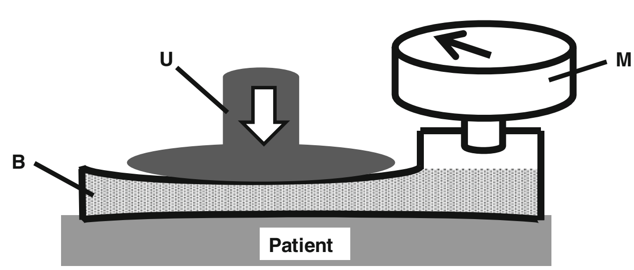

Fig. 1 The probe (*U*) pressure (*white arrow*) is conducted through the water-filled bag (*B*) to the manometer (*M*)

was placed in the IJV, an open-ended plastic tube was vertically connected, which allowed blood to run out from the IJV until equivalent to the venous pressure (P_v). We routinely perform this method to confirm the needle is in the vein, not in the artery. The P_v value was determined as a sum of the height of the blood in the tube from the skin and the depth of the IJV from the skin measured by US. All the patients were placed in supine position, because the P_v values and P_{tc} values might have a large variation if the patients were not supine. All the patients whose position was modified from supine during the procedures were excluded from this study. The values of P_{tc} and P_v were measured in inspiratory period. The relationship between P_{tc} and P_v was studied.

The patients were divided into two groups based on the number of attempts: those requiring three attempts or more ($\geq$3 attempts) was designated the "difficult group" and fewer than three attempts (<3 attempts) was considered the "easy group." This limit of three attempts was based on the previously reported average number of attempts, which was fewer than three using US and more than three without US [1, 4]. If the number of attempts was more than five, we tried infusion and/or changing position, and these cases were excluded. We compared the IJV diameters (vertical and horizontal) and the P_{tc} values between the two groups.

For statistical analyses, the two-tailed *t* test was used between the groups. Correlation analysis and paired *t* test was used between the values of P_{tc} and P_v.

Forty-seven patients were included, divided into two groups (see Table 1). Four patients required more than five attempts. We tried infusion and/or changing position for these patients and succeeded in catheterization in all such cases. These patients were excluded from this study.

- The relationship between P_{tc} and P_v

Measured P_v values were 1.0–16.8 cmH_2O and P_{tc} values were 2.0–18.0 cmH_2O. The correlation was as follows: $P_{tc} = 0.87\ P_v + 2.1$, $r = 0.91$ (Fig. 2). The values of P_{tc} were significantly higher than those of P_v; the average difference was 1.3 ± 1.8 (SD) cmH_2O, $P < 0.0001$.

- Relationship between P_{tc} and number of attempts

Thirty-three patients were in the easy group and 14 patients were in the difficult group. The profiles of these groups were summarized in Table 1. The easy group showed significantly larger vertical diameter and P_{tc} value than the difficult group.

Figure 3 is the scatter plot of two groups. The maximum P_{tc} value in the difficult group was 5 cmH_2O and the minimum value in the easy group was 6 cmH_2O; a clear difference was observed between them.

This study may be the first report of US pressure measurement favorable for easy CVC insertion. Previously,

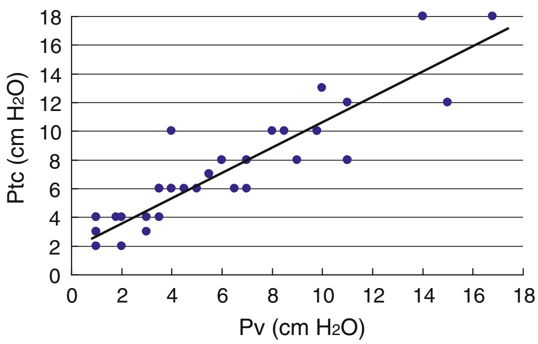

Fig. 2 Relationship between venous pressure (P_v) and the transcutaneous probe pressure at which the vein is collapsed (P_{tc}). Cases of same P_v and P_{tc} are indicated by the *dot regression line*: $P_{tc} = 0.86\ P_v + 2.2$, $r = 0.91$

Table 1 Group profiles

	Easy group	Difficult group	*P*
Number of patients	33	14	
Number of attempts	1.2 ± 0.4	3.7 ± 0.7	
Age (years)	66 ± 10.5	71 ± 8.8	0.14
Gender (male/female)	18/15	10/4	0.34
Sepsis	11 (33.3%)	3 (21.4%)	0.50
Lung disease	2 (6.1%)	1 (7.1%)	1.00
Cardiovascular disease	5 (15.2%)	1 (7.1%)	0.65
Gastrointestinal disease	9 (27.3%)	6 (42.9%)	0.32
Horizontal diameter (mm)	14.7 ± 3.9	13.4 ± 4.0	0.36
Vertical diameter (mm)	9.2 ± 3.1	6.8 ± 2.2	0.013
Value of P_{tc} (cmH_2O)	9.3 ± 3.8	3.5 ± 0.9	<0.0001

Easy group, fewer than three attempts were required; Difficult group, three or more attempts were required. Data are expressed as mean ± SD

P_{tc}, transcutaneous venous occlusion pressure

Baumann et al. [12] studied IJV collapsing by US as a substitute for central venous pressure. Most physicians believe real-time US guidance requires much time and labor, which results in reduction of use of this method [9].

Although the number of excluded cases was small, we were able to puncture successfully by infusion and/or by changing position in all cases. If we predict ease of puncture by using this device and control the collapsibility of the IJV before puncture, we can perform safer catheterization.

P_{tc} and P_v have a good interrelationship, and in most cases P_{tc} values were a little higher than P_v; we think this is because P_{tc} may be generated not only by the IJV pressure but also by the venous wall elasticity and pressure of the extravascular tissues and muscles. Sustainability of the vein may be the key factor for easiness of IJV puncture, so P_{tc} may be unique for estimation of the difficulty in catheterization before puncture. This P_{tc} value should be more than 6 cmH_2O for easy puncture in this study.

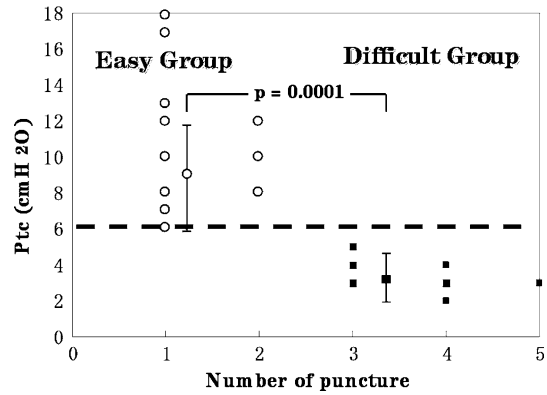

Fig. 3 *Open circles* show cases in the easy group (fewer than three venipuncture attempts); *quadrilateral dots* show cases in the difficult group (three or more venipuncture attempts required). Cases of the same P_{tc} and number of attempts are indicated with the same dot. The mean P_{tc} value of the easy group was significantly higher than that of the difficult group. *Dashed lines* indicate minimum P_{tc} of 6 cmH_2O in easy group; all values of the difficult group are below the line. There is a clear threshold pressure between them

Our study has some limitations. Although the P_{tc} value was blinded, the physician who punctured the IJV was able to know the venous collapsibility itself during US screening. This study was performed in a single institution, and all the procedures were done by a single physician. Further studies are needed, especially concerning the threshold P_{tc} value. However, it is undoubtedly true that P_{tc} is strongly related to ease of catheterization.

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