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Assessment of the deformation rate of venous diameter during internal jugular vein puncture using a newly developed thin-tip three-dimensional needle

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Abstract

Background: The internal jugular vein (IJV) is one of the most used sites for central venous access. Some authors revealed the association of a higher deformation rate of the IJV wall with posterior wall penetration, which may cause a hemorrhagic complication. A newly developed thin-tip needle (three-dimensional (3D) needle) reduced the deformation rate in an ex vivo study. Therefore, we conducted a clinical study to investigate its efficacy in reducing vessel deformity during IJV puncture.

Methods: This study retrospectively enrolled 80 adult patients who received central venous port (CVP) implantation via the IJV from April 1, 2022, to November 10, 2023, in our institution. Traditional needle-and-catheter was used for ultrasound (US)-guided IJV puncture (usual group) for the former 40 patients before July 18, 2023. Afterward, the 3D needle was used for the latter 40 patients (3D needle group). US images were stored and analyzed to calculate the deformation rate.

Results: The deformation rate was 58.6% (13.2–100) for the usual needle and 41.8% (10.6–100) for the 3D needle ($p=0.0034$). Patients who required several punctures included 2 for the usual needle and 12 for the 3D needle, respectively ($p=0.0032$). All patients and the usual needle group demonstrated a weak negative correlation between the deformation rate and pre-puncture vessel diameter ($r=0.24$ and 0.41, respectively), with no correlation in the 3D needle group.

Conclusion: The deformation rate of the IJV wall was smaller in the 3D needle group than in the usual needle group. The use of a 3D needle would be safer when puncturing the IJV.

Keywords

Central vein puncture, US-guided procedure, interventional radiology, new devices, oncology access, techniques & procedures

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Introduction

The internal jugular vein (IJV) is one of the most used sites as a central venous access. Previously, the landmark method in which the operator punctures the vein that targets an anatomical landmark, such as the common carotid artery, sternocleidomastoid muscle, and nipple, was the mainstay. Currently, real-time ultrasound (US) guidance has become a standard practice that considers patient safety.[1]

On the other hand, IJV puncture inherently can lead to a severe complication like arterial puncture, hematoma

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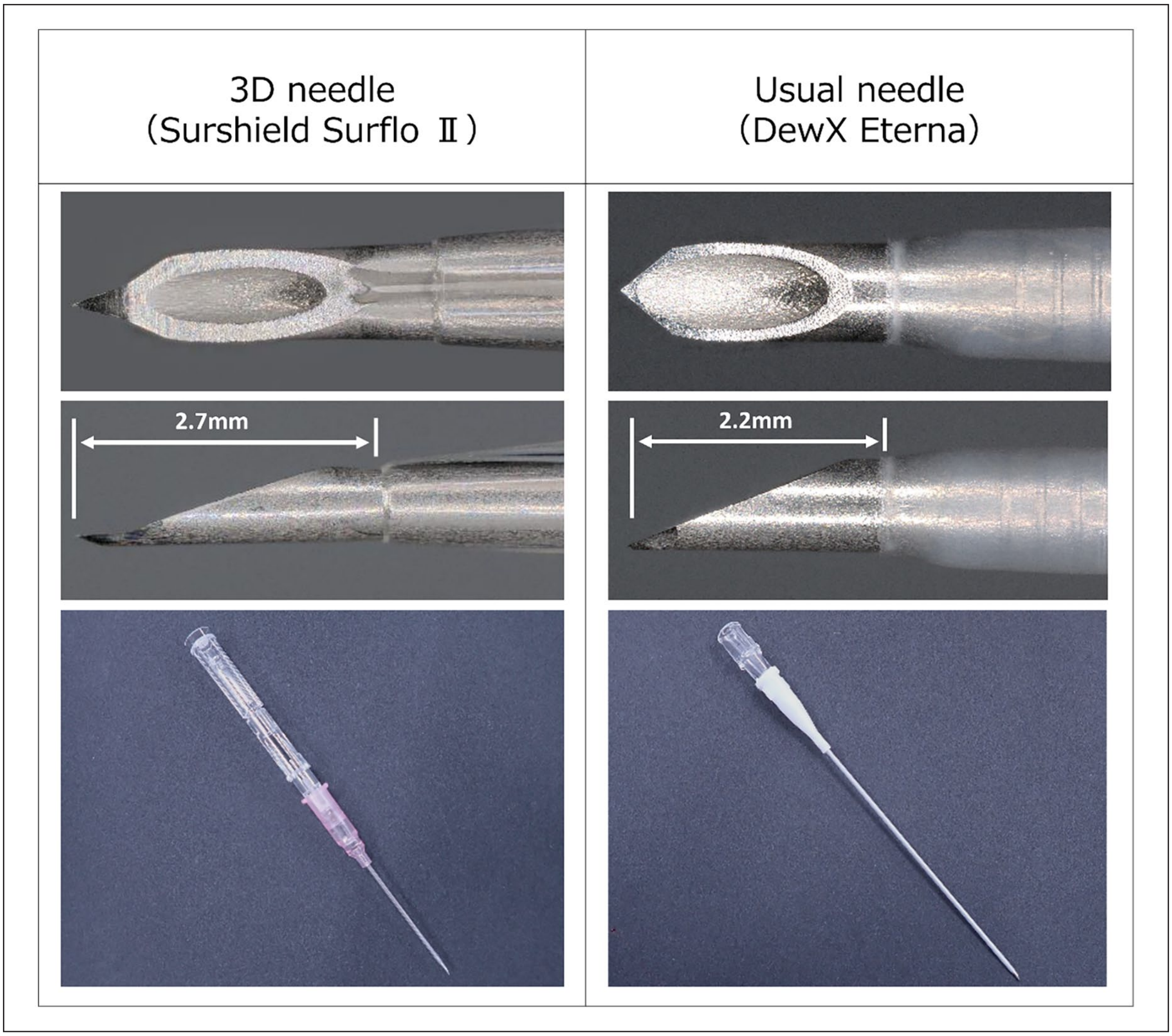

Figure 1. 3D and usual needle.
Upper and middle row: 50 times optical scope image showing the tip of needle and outer cannula. Lower row: actual appearance of needles.

that compromises the airway, hemothorax, pneumothorax, and air embolism, which are life-threatening.[2] Some of these complications are generally associated with posterior wall puncture.[3]

Recently, a short bevel needle with a thin tip was developed.[4] This needle demonstrated a low resistance on its tip when puncturing veins because of its three-dimensional (3D) design, which is intended for peripheral vein puncture. We hypothesize that this 3D needle is useful for central venous puncture, like IJV.

Generally, we believe that this 3D needle is superior to a traditional needle, but whether or not this needle decreases vein deformation remains unclear. A significant difference would reduce the posterior wall puncture.

Thus, the current study clarifies that the deformation rate of IJV by the 3D needle is less than that of the traditional needle on real-time US guided puncture.

Materials and methods

This retrospective study comprised 80 adult patients who received central venous port (CVP) implantation via the internal jugular vein (IJV) from April 1, 2022, to November 10, 2023, in our institution. Among them, a traditional needle in a commercially available CVP kit (Dewx eterna; Terumo Corporation, Tokyo, Japan) was used for the former 40 patients before July 18, 2023 (usual needle group). The 3D needle (Surshield Surflo II; Terumo Corporation, Tokyo, Japan) was used for IJV puncture in the latter 40 patients (3D needle group; Figure 1). The ethics committee of our institution approved this protocol (number 6287) and waived the additional informed consent. Every patient was informed and consented to undergo the procedure.

The deformation rate was calculated as follows (Figure 2):

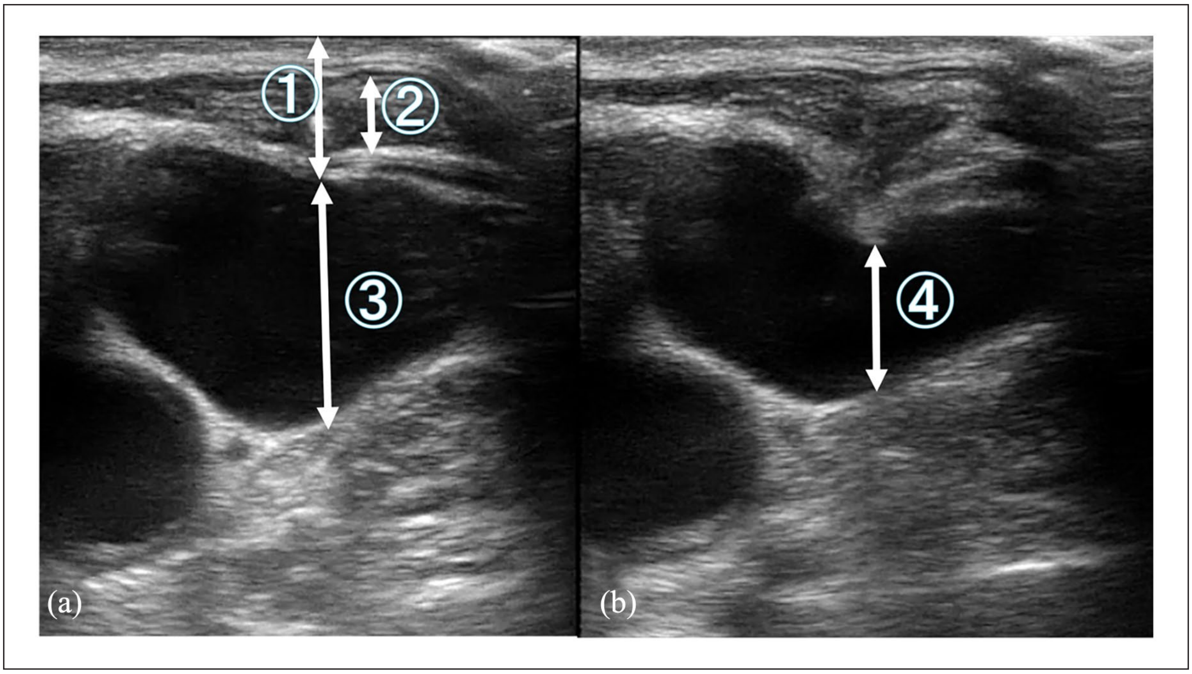

Figure 2. US measurements: (a) 1: depth of anterior wall of the vein, 2: sternocleidomastoid muscle width, 3: vessel diameter (pre) and (b) 4: vessel diameter (post).

Table 1. Patient characteristics.

Variable	Type of needle		*p* Value
	Usual	3D	
Age (years)	70 (32–87)	68 (24–84)	0.4353
Sex (male/female)	17/23	22/18	0.2634
Height (cm)	158.4 (144–172.3)	161 (148–181)	0.0166
Weight (kg)	51.4 (35.7–108.1)	53.7 (38.9–101.4)	0.4529
BMI (kg/cm^2)	21 (14.9–39.7)	19.4 (16.3–39.6)	0.3918
Indication of port placement (chemotherapy vs TPN)	30: 10	33: 7	0.4113

Numbers are indicated as median (range).

$$\text{Deformation rate } (\%) = ((\text{vessel diameter } (\text{pre})) - (\text{vessel diameter } (\text{post})) / \text{vessel diameter } (\text{pre})*100$$

The indication for port placement was whether it was for chemotherapy treatment of a malignant tumor or for receiving total parenteral nutrition. An experienced physician (3–25 years of experience, eight physicians) performed port placement. Patients treated by a junior operator who had treated <15 patients were excluded because they were accompanied and assisted by an experienced operator per hospital protocol.

Extracted information from medical records included US video during the puncture, age, sex, height, body weight, port placement date, port placement indication, success at first puncture attempt, puncture success, time needed to puncture, and complications (arterial puncture, hematoma, and posterior wall puncture). Board-certified radiologists were labeled as “certified” operators, and a comparison between certified and noncertified operators was performed. Table 1 shows patient characteristics. A difference was found in patient height between the usual needle and 3D needle groups. Other variables were not different between the two groups.

Puncture success was a successful blood drawing from the outer needle cannula. The time needed to puncture is the time between needle placement at the incision and successful blood drawing from the outer cannula. Posterior wall puncture was defined as 1, where the needle tip is visually advanced beyond the posterior vein wall on US, and 2, where blood cannot be drawn from the outer cannula

Table 2. Ultrasound measurements.

	Type of needle		p Value
	Usual	3D	
Deformation ratio	58.6 (13.2–100)	41.8 (10.6–100)	0.0034
Procedure time (s)	30.6 (8.6–353.2)	28 (10.1–113.3)	0.9846
Major bleeding	0	0	1
Posterior wall penetration	2	1	0.5525
Patients needed several punctures	2	12	0.0032
Arterial puncture	0	0	1
Depth of vessel (mm)	9.1 (5.0–17.7)	8.2 (3.8–20.6)	0.2854
SCM width (mm)	4.0 (1.1–10.4)	4.1 (0.7–9.6)	0.5035
Vessel diameter (pre: mm)	9.4 (3.0–18.6)	8.1 (2.2–16)	0.7802
Vessel diameter (post: mm)	4.2 (0–15.2)	4.6 (0–12.7)	0.1088

For deformation ratio, numbers are indicated as average (range). Otherwise, numbers are indicated as median (range).

when the needle tip could not be visualized on US while the proximal side of the needle was going through the vessel lumen.

Details of needles used (See Figure 1)

The 3D needle (Surshield Surflo II)

The needle is made for a usual peripheral venous cannulation. It consists of a 20-gauge polyurethane catheter (length: 32 mm) and a 22-gauge stainless needle with a short bevel and a thin tip.

The usual needle (Dewx eterna)

The needle is made for a central venous cannulation. It consists of a 20-gauge polyethylene catheter (length: 65 mm) and a 21-gauge stainless needle with a short bevel.

US-guided IJV puncture

The operator stands cranial to the patient, whose head is turned on the opposite side of the puncture (approximately 30° from midline). US (CANON Xario 200 7.5-MHz linear probe (CANON, Tokyo, Japan), Sonosite S II 6-13 MHz linear probe (Fujifilm, Tokyo, Japan)) was placed transversely over the patient's neck to observe IJV in the short axis. A needle guide was not used. Under maximal barrier precaution, local anesthesia was applied and a small incision (up to 5 mm) was made. The needle (either usual or 3D) was then advanced through the incision slowly to the venous wall, being perpendicular to the US probe under real-time US guidance. The angle between the needle and the vein was intended to be 45°. Video recording and timer were started after placing the needle at the incision. Once the needle tip was visualized at the venous wall on the US screen, operators punctured the vein with a quick snap movement, to minimize vascular wall tenting and cautious enough to avoid posterior wall penetration. The puncture was performed under the Valsalva maneuver whenever possible. The inner needle was withdrawn after visual confirmation of the needle tip in the vein, and a syringe drew blood out to confirm that the tip of the outer cannula was within the vein. The timer was stopped.

US video analysis

Videos stored in the US machine were extracted and converted to still images every 10 frames/s using freely available software (GOM player; https://www.gomlab.com/gomplayer-media-player). Two images were selected manually when the diameter of the vein was maximum before the puncture and when the vein was most deformed by the needle. The two images were analyzed with another software (ImageJ; https://imagej.net/ij/) to extract the following: depth of the anterior wall of the vein, SCM thickness intervening in the needle path, maximum diameter of the vein, and most deformed diameter of the vein (Figure 2).

Statistics

Continuous variables were evaluated using the Mann–Whitney U test. Pearson's chi-square test was used to assess the differences between the two groups for categorical variables. The element affecting the deformation rate was investigated by univariate analysis. Statistical significance was set at p-values of <0.05. The correlation coefficient r was evaluated using the Pearson method.

Results

The deformation rate was 58.6% (13.2–100) and 41.8% (10.6–100) for the usual and 3D needles, respectively ($p=0.0034$). Patients who required several punctures included 2 and 12 for the usual and 3D needles, respectively ($p=0.0032$). The two groups demonstrated no difference regarding puncture success or time needed to puncture, major bleeding, posterior wall penetration, and arterial puncture (Table 2).

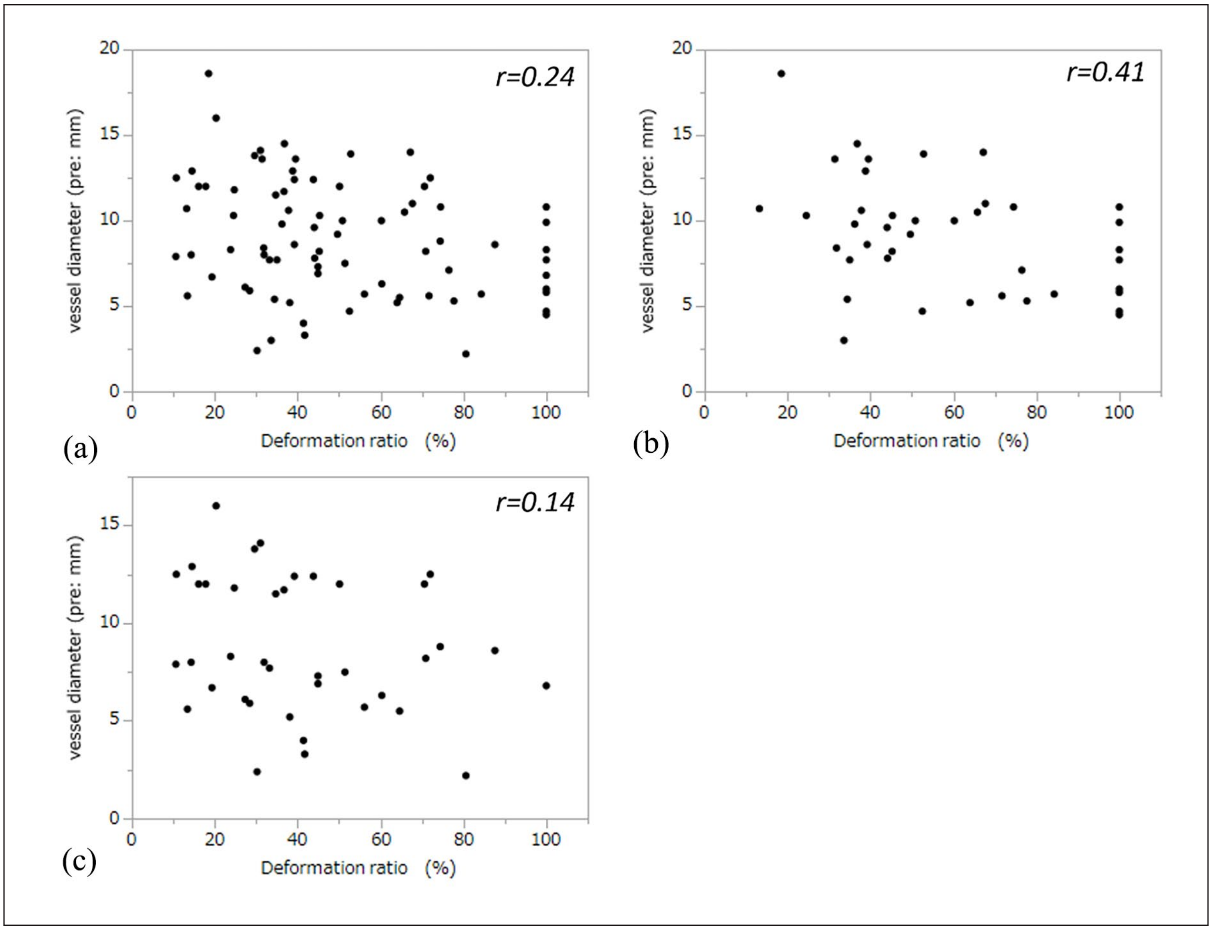

Figure 3. Correlation between the deformation ratio and pre-puncture vessel diameter: (a) the entire patients showed a weak correlation between the deformation ratio and pre-puncture vessel diameter ($r = 0.24$), (b) the usual group showed stronger correlation than the entire patients ($r = 0.41$), and (c) in the 3D needle group, there was no correlation between the two ($r = 0.14$).

Table 3. Deference between certified physician and non-certified.

	Certified	Not certified	*p* Value
Number of procedures			
3D	13	27	
Usual	23	17	0.0246
Patients needed several punctures			
Once	30	36	
More than once	6	8	0.859
Deformation ratio			
Overall	44.1 (10.7–100)	43.3 (10.6–100)	0.6738
3D	41.4 (10.7–87.6)	34.7 (10.6–100)	0.5347
Usual	45.2 (13.2–100)	60.2 (31.4–100)	0.2216

Numbers are indicated as median (range).

A weak negative correlation was observed between the deformation rate and pre-puncture vessel diameter together with the usual needle group and the 3D needle group ($r = 0.24$; Figure 3). The prepuncture vessel diameter demonstrated a moderate correlation with the deformation rate in the usual needle group ($r = 0.41$), but a correlation was not observed between the diameter in the 3D needle group and the deformation rate ($r = 0.14$).

The number of procedures performed by certified and noncertified radiologists was statistically different across

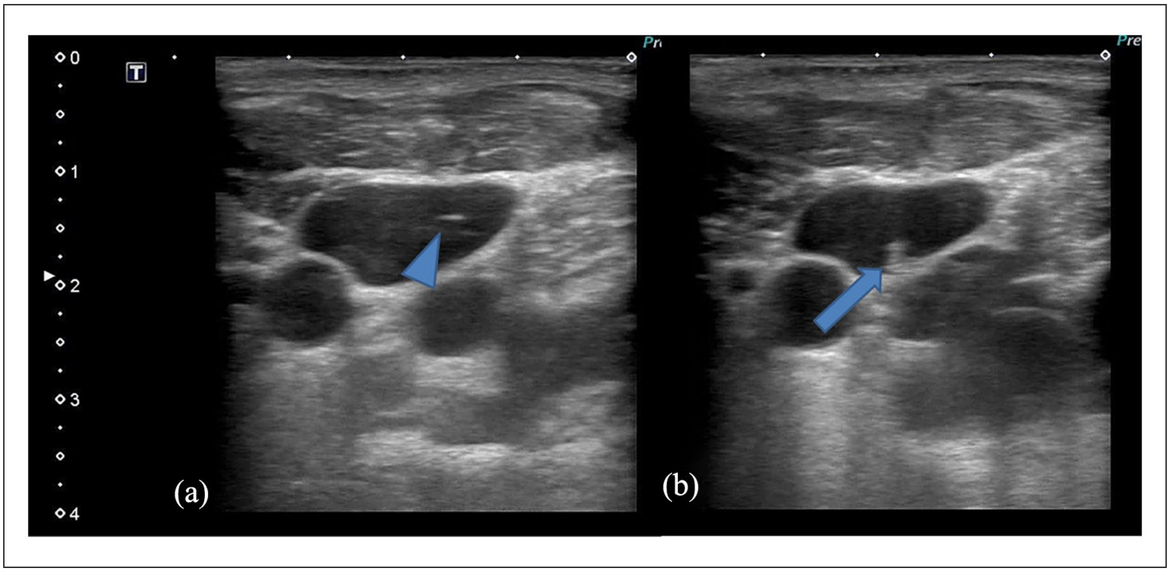

Figure 4. Tip of 3D needle: (a) tip of 3D needle (arrowhead) often proceeds to the vessel lumen without a noticeable resistance, unlike the usual needle. However, the outer cannula is still outside the vessel wall (Note that gauge on the left is indicated as centimeters). (b) Operator then pushed the needle further (arrow), for the outer cannula to get into the lumen. However, the blood could not be drawn back from the outer cannula and deemed as failure to puncture. A possible tenting was suspected outside the US image.

groups ($p=0.0246$). Patients who needed several punctures were not different between groups. Deformation rates in the overall, 3D, and usual groups were not different between groups (Table 3).

Discussion

The 3D needle revealed a lower deformation rate than the conventional needle. Tanabe et al. revealed less vessel deformity with the 3D needle in an ex vivo model simulating human forearm with tourniquet application, compared with other peripheral intravenous catheters.[5] IJV puncture differs from forearm venipuncture in respect of vessel diameter, vessel wall thickness, intervening soft tissue such as muscle and skin, and lack of tourniquet application. Regardless of the differences, our data revealed a decrease in vessel deformity during the 3D needle puncture in human IJV as well.

The number of punctures needed and their deformation rate were not different between certified and non-certified operators. Brass et al. revealed no sufficient evidence of whether or not experienced operators reduce complications on US-guided IJV puncture.[1] Hence, the development of a superior needle would be important to reduce complications regardless of the operator's skill and experience.

Posterior wall penetration demonstrated no difference between the groups, but greater deformation of the vessel wall poses a greater risk of posterior wall puncture. Posterior wall puncture may cause inadvertent injuries of posteriorly positioned arteries to the IJV and subsequent critical cervical hematoma,[6,7] thus a needle with less vessel wall deformation would be safer.

Yoshida et al. revealed that a small venous diameter was associated with posterior venous wall penetration in human IJV.[3] Our study revealed a weak negative correlation between the prepuncture vessel wall diameter and the deformation rate when 3D and usual needles are combined. However, only the conventional needle group demonstrated a correlation between the two when we looked into the subgroup. Thus, the risk of posterior wall puncture increases when puncturing veins with a small diameter using the conventional needle. A 3D needle is not free from vessel deformation, but it may be safer to use when puncturing small IJVs compared with conventional ones.

The number of puncture attempts was greater in the 3D needle group. The 3D needle tip is sharp and sometimes enters the vessel lumen with almost no "tenting," while the outer cannula is still outside the vessel. It was felt that this phenomenon is unique to the 3D needle. The operator would recognize this as if the entire needle was already in because the tip was actually in the lumen on the US screen. This leads to premature inner needle withdrawal and subsequent failure of blood drawing, which results in increased puncture attempts (Figure 4). We speculate that the difference in resistance between the needle tip (length: 2.7 mm) and the outer cannula is higher in the 3D needle. The operator should recognize this phenomenon as a potential pitfall, because the increased venipuncture attempts are associated with endothelial damage which is the mechanism underlying catheter-related venous thrombosis.[8,9]

The length of the 3D needle is 32 mm, which can be used with a US puncture guide apparatus. A needle guide is typically effective for beginners to easily and safely puncture the vessel.[10,11] A 3D needle and needle guidance would be beneficial to reduce complications and accidents.

This study has some limitations. First, this is a single-center, retrospective study. Lack of randomization may cause unaware bias between the groups. Second, the operators were not randomly allocated. Additionally, the free-hand puncture method instead of using a puncture guide apparatus may affect the degree of needle tip visualization and vessel deformity. Third, the number of patients enrolled was relatively small. Hence, the number of complications was too small to compare or estimate the degree between the groups.

Conclusion

The deformation rate of the IJV wall was smaller in the 3D needle group than in the conventional needle group. The use of a 3D needle would be safer when puncturing the IJV compared to conventional needles.

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Author contributions

Kazuki Hashimoto is a corresponding author. Shintaro Nawata, Shinji Wada, Shingo Hamaguchi performed procedure, data collection and did intellectual contribution. Kenichiro Tanabe gave advice for statistical analysis and did intellectual contribution. Hidefumi Mimura gave instruction and did intellectual contribution.

Declaration of conflicting interests

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Ethical approval

The ethics committee in our institution approved this study protocol (number 6287).

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Supplemental material

Supplemental material for this article is available online.

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