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Optimal head rotation angle for safe right internal jugular vein catheterization using out-of-plane approach: an ultrasonography study

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Abstract

Aim: The most common complication following internal jugular vein catheterization is the puncture of the common carotid artery. We aimed to find an optimal head rotation angle for safe vein catheter insertion while minimizing the risk of artery puncture. **Materials and methods:** Eighty-two patients admitted to the intensive care unit were included in the prospective study. Ultrasound examination of the neck vessels on the right side was performed in the neutral position and at a head rotation of 15°, 30°, 45° and 60° to the left. Internal jugular vein and common carotid artery puncture angle, overlapping angle of vein by artery and vein safe puncture angle were evaluated. **Results:** The internal jugular vein puncture angle increased with head rotation from the neutral position to 30° and 45° and was largest at 60° ($p<0.001$ for all). The overlapping angle increased significantly at 45° and 60° rotation compared with the neutral position ($p<0.001$ for all). The vein safe puncture angle was highest at 30° and significantly different from the neutral position and 60° ($p=0.003$ and $p=0.013$, respectively). **Conclusions:** When performing right internal jugular vein catheterization without ultrasound guidance by using an out-of-plane technique, the head should be rotated at 30°, because the overlapping angle increases with further head rotation and can increase the risk of artery puncture.

Keywords: jugular vein; common carotid artery; ultrasound; anatomic model

Introduction

Critically ill patients often require reliable central venous access in order to administer intravenous fluids, blood products, parenteral nutrition or medications, to monitor central venous pressure or other hemodynamic indexes and to perform renal replacement therapy. Jugular, subclavian, and femoral veins are the major insertion sites. The reported incidence of mechanical complications following central venous catheterization is between 1.1% and 17% and depends on its definition [1]. Among the most frequently reported mechanical complications are accidental artery puncture, bleeding, hematoma, pneumothorax or hemothorax. Internal jugular vein (IJV) catheterization has a lower risk of mechanical complications than the subclavian vein [2]. The common mechanical complication following IJV catheterization is puncture of the common carotid artery (CCA) and its incidence was found to be from 10% to 12% using landmark technique catheterization compared to 1-4% using ultrasound-guided catheterization [3-5]. The risk of accidental CCA puncture may be related to anatomic variations of the IJV, specifically, its shape and relationship to

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the artery. However, in some retrospective design studies, the incidence of artery puncture was not reported [1]. The traditional anatomical landmark approach is used to find the correct place in which to insert catheters. IJV is easily accessible for ultrasonographic visualization, so ultrasound (US) can help to assess the patency of the vessel, the presence of a thrombus in the lumen and the anatomical relationship between the IJV and CCA. Current evidence-based recommendations emphasize that US should be used whenever possible to guide this procedure [2,6]. US guidance increases the central venous catheterization success rate, reduces the time and number of attempts until successful catheterization and reduces the incidence of mechanical complications when compared with the traditional landmark approach [3-5,7,8].

Basic training of cannulating the IJV by the landmark technique is still recommended, as US may not be available in all in-hospital settings. In a practitioners' survey, the most frequently reported barriers to the use of US guidance were limited access to US equipment, perception of increased total procedure time and concern for loss of landmark skills [9]. In addition to this, the identification of head rotation angle for safe IJV catheterization is important, because US-guided catheter insertion sometimes cannot be done, as it must be performed as quickly as possible in an emergency situation or the US device is not available at the bedside. The aims of this study were to evaluate the influence of head rotation angle on the IJV cross-sectional parameters (in order to find an optimal head rotation angle for safe vein catheter insertion while minimizing the risk of artery puncture) and the anatomic relationship with CCA in patients admitted to the intensive care unit.

Materials and methods

This prospective observational study was conducted at the mixed medical-surgical intensive care unit of the Republican University Hospital Vilnius, Lithuania. The study population included consecutive adult patients admitted to the intensive care unit over a 2-month period between 17 October 2017 and 16 December 2017. The study was reviewed and approved by the Vilnius Regional Biomedical Ethics Committee (protocol number 158200-18/9-1058-559) under a waiver of signing informed consent, as the study posed a minimal risk to subjects. To find a detection of significant differences in overlap angle a minimum of 29 patients with alpha of 0.05 and power of 80% had to be included. The exclusion criteria were as follows: cervical spinal cord trauma, tracheostomy or previous surgeries of the neck, unstable hemodynamics, documented chronic heart disease, catheterized right IJV, raised intracranial pressure requiring constant head-of-bed elevation, absence or thrombosed IJV and verbal disagreement to participate.

Patients' demographic data were collected from the medical records. US evaluation was performed using a portable GE Logiq Book XP equipped with an 8L-RS linear 4- to 10-MHz frequency probe. Images were visualized using B mode with a preinstalled "vascular" set of parameters (corresponding to 8-MHz frequency and 4-cm depth of penetration) being selected. The patient was placed in the supine position with no head elevation. The patient's head lay in the neutral position and was then turned 15°, 30°, 45° and 60° to the left side, as verified using an adjustable protractor, and US examination was performed. An US probe placement was selected in a transverse plane on the right side of the patient's neck at the level of the middle-triangle level because of the higher needle insertion point usually at a top of a triangle for landmark guided technique. A triangle consists of anatomical landmarks: a base was clavicle, its sides – heads of sternocleidomastoid muscle. Middle-triangle level was a horizontal line, connecting midpoints of both sides and parallel to clavicle. At that point, the cross-sectional diameter of the right IJV and CCA was measured. IJV and CCA were identified according to changes in form with an application of gentle pressure and color Doppler imaging results. To minimize respiration-related motion artefacts for conscious patients, all acquisitions were performed during a short breath hold at the end of inspiration. For patients on mechanical ventilation, the same principles applied, with tidal volume set at 7 mL/kg of predicted body weight and positive end-expiratory pressure at 5 cm H_2O. For measurements, all images were frozen with as minimal pressure applied as needed to obtain a quality image (so as not to deform blood vessels) and saved in the device's internal memory.

The US image was centralized on the CCA and the position of the IJV was assigned to one of the 12 positions relative to the CCA (1 to 12) using a circular form with numbers corresponding to hours on a clock's face. All IJV positions were grouped into 8 different segments: 12 hours on clock, anterior; 1-2, anterolateral; 3, lateral; 4-5, posterolateral; 6, posterior; 7-8, posteromedial; 9, medial; 10-11, anteromedial.

Measured variables

The cross-sectional area of the right IJV (width, height and flattening) and its adherence to CCA were evaluated. Measurements of IJV width and height were performed using the US device's software on the neutral position and during head rotation. Flattening was defined as the width and height difference divided by width. The lower flattening value means that the vein shape is more

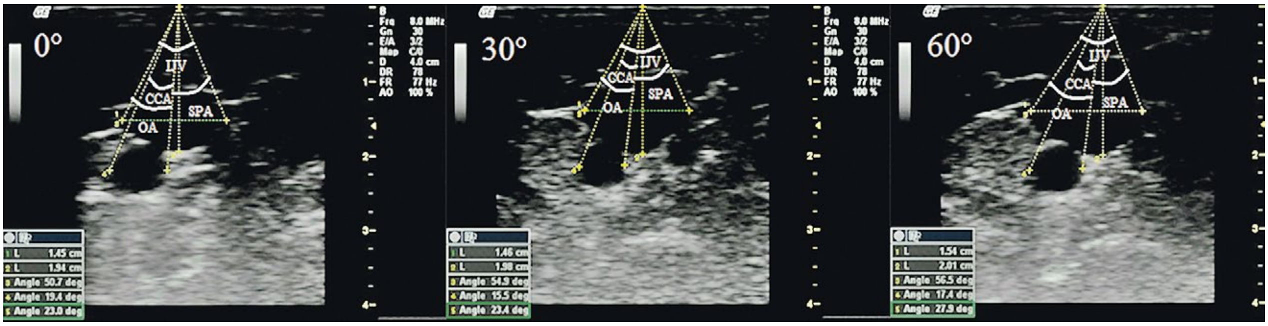

Fig 1. The measurement of puncture angles of the internal jugular vein and common carotid artery, overlap angle, and internal jugular vein safe puncture angle. IJV, internal jugular vein puncture angle; CCA, common carotid artery puncture angle; OA, overlapping angle (represents part of internal jugular vein's angular width covered by artery); SPA, internal jugular vein safe puncture angle (equal to IJV and OA difference).

circular. A total of four angles were calculated: IJV puncture angle, CCA puncture angle, overlapping angle (OA) and IJV safe puncture angle similarly to the approach employed by Saitoh et al [10] (fig 1). The IJV puncture angle was measured by drawing straight lines from the skin access point (chosen as a dot directly over the IJV center) to the vein's leftmost and rightmost points. For measuring the CCA puncture angle, the skin access point was chosen to be the same as the vein. OA was defined as a part of the IJV angle, which overlaps with the CCA angle. The IJV safe puncture angle was defined as the IJV puncture angle and OA difference. Optimal head rotation is defined as an angle at which the probability of the IJV safe puncture will be the highest.

Statistical analysis

All data are expressed as means ± standard deviation. Microsoft Excel 2013 (Microsoft, Redmond, WA, USA) was used for data input and manipulation and IBM SPSS 25.0 (IBM Corporation, Armonk, New York, USA) was used for statistical analysis. For two continuous variables, Pearson's (for normally distributed variables) or Spearman's (for no normally distributed variables) correlation coefficients were calculated. If normality criteria was met, Student's t-test for comparison of means from two different samples was used, otherwise – nonparametric test with Mann-Whitney U criteria was applied. If comparison of means was performed from three or more different samples, one-way analysis of variance was used instead. A p-value <0.05 was considered significant.

Results

A total of 82 patients were included in the study. The mean age of the patients was 65.5±17.2 years. Forty-six (56.1%) patients were male and 31 (37.8%) patients were on mechanical ventilation. No significant differences between IJV cross-sectional parameters and puncture angles were found regarding patient's age, gender and ventilation status. At the neutral position, the IJV was most commonly (57.4%) laid on the anterolateral and lateral segments (corresponding to 1-3 hours on the clock dial), while the anterior and anterolateral segments (12-2 hours on the clock dial) were more prevalent (65.9%) at 60° of rotation. The IJV in atypical positions (medial-posterior segments) was found in 9.8% of the patients.

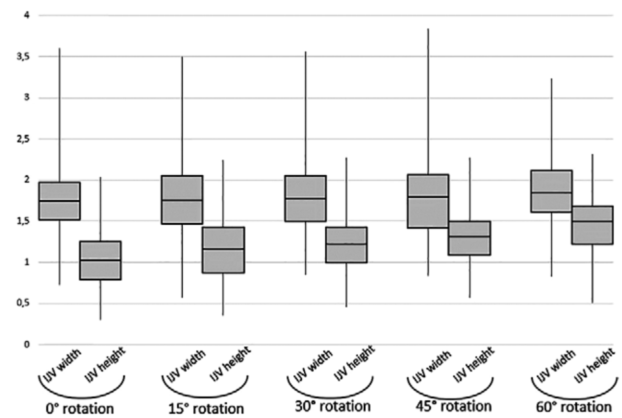

Fig 2. The impact of head rotation angle (0°, 15°, 30°, 45° and 60°) on width and height of the internal jugular vein. Box plot with highest, lowest values, first and third quartiles, and median value is shown.

The IJV width during head rotation increased marginally and was not significantly different when compared among all head positions. The IJV height at 30° rotation height differed significantly from its height in the neutral position (p<0.05). However, IJV height differences were found to be more significant with further head rotation at 45° and 60° as compared with the neutral position (p<0.001 for both comparisons). In the neutral head position, the shape of the IJV on average was more oblate and took a form of an ellipse. IJV flattening decreased and became more circular when the head was rotated. The IJV

Table I. Internal jugular vein width, height, flattening, and puncture angle; common carotid artery puncture angle; overlap angle; and safe puncture angle depending on different head rotation positions (0°, 15°, 30°, 45°, and 60°).

Parameter	**Neutral (0°)**	**15°**	**30°**	**45°**	**60°**
IJV width (cm)	1.77±0.57	1.79±0.56	1.80±0.56	1.81±0.56	1.85±0.51
IJV height (cm)	1.05±0.38	1.16±0.40	1.21±0.36*	1.33±0.34**	1.44±0.36**
IJV flattening	0.39±0.17	0.34±0.16	0.31±0.16	0.24±0.17**	0.20±0.17**
IJV puncture angle (°)	63.7±18.9	69.1± 20.7	77.3±21.8**	83.3±23.5**	87.3±22.9**
CCA puncture angle (°)	18.9±5.6	18.6±5.4	19.1 ±5.5	18.9° ± 5.3	19.1±5.6
Overlap angle (°)	20.8± 11.4	22.0±11.6	22.9±11.9	32.6±13.0**	41.6±15.9**
IJV safe puncture angle (°)	42.9±16.8	47.1±19.1	54.5±20.0**	50.7±22.2	45.2±21.9

IJV, internal jugular vein; CCA, common carotid artery. Data are expressed as means±standard deviation. *Denotes p<0.05 when compared with the neutral (0°) position. **Denotes p<0.001 when compared with the neutral (0°) position.

cross-sectional area was largest at 60° rotation (fig 2). The IJV flattening value was almost twice as small when the head was rotated from the neutral position to 60°. The IJV puncture angle consistently increased with head rotation from the neutral position to 30° and 45° and was largest at 60° rotation (for all comparisons, p<0.001; Table I). The CCA puncture angle was almost stable during head rotation as compared with the neutral position.

The IJV puncture angle and OA were smallest in the neutral position. The OA remained almost the same at the first three positions (neutral position, 15° and 30°) but further increased significantly at 45° and 60° of head

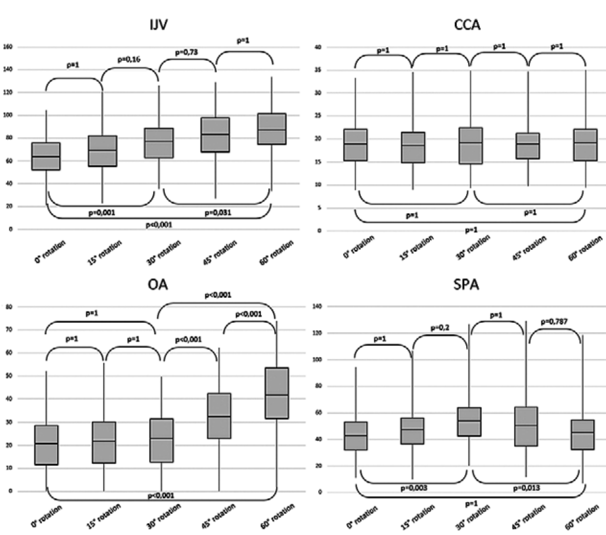

Fig 3. The impact of head rotation angle (0°, 15°, 30°, 45° and 60°) on the right internal jugular vein puncture angle, common carotid artery puncture angle, overlapping angle, and internal jugular vein safe puncture angle. Box plot with highest, lowest values, first and third quartiles, and median value is shown. *p* values are provided. IJV, internal jugular vein puncture angle; CCA, common carotid artery puncture angle; OA, overlapping angle (represents part of internal jugular vein's angular width covered by artery); SPA, internal jugular vein safe puncture angle (equal to IJV and OA difference).

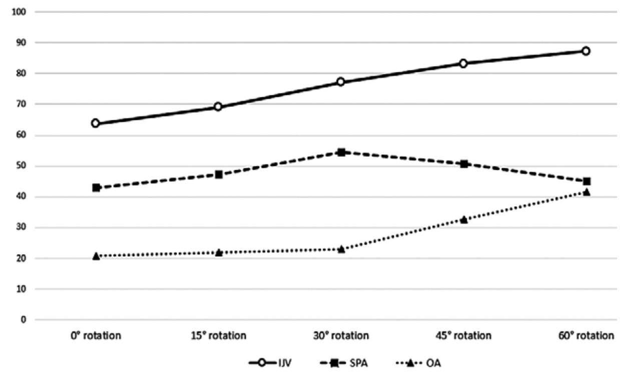

Fig 4. Internal jugular vein angle consistently increases with further head rotation, while the overlap angle stays mostly the same in the first three positions (0°, 15°, 30°) but increases significantly at 45° and 60° rotation. The puncture angle, accordingly, increases from 0° to 30° rotation but decreases in later positions. IJV, internal jugular vein puncture angle; OA, overlapping angle (represents part of internal jugular vein's angular width covered by carotid artery artery); SPA, internal jugular vein safe puncture angle (equal to IJV and OA difference).

rotation compared with the neutral position (p<0.001 for both). The IJV safe puncture angle increased gradually when rotating from the neutral position to 30°, but it further decreased at 45° and 60° head rotation (fig 3). When the head was rotated at 60°, both the IJV puncture angle and OA increased resulting in the same IJV safe puncture angle as in the neutral position. The IJV safe puncture angle was highest at 30° and significantly different from the angle at the neutral position and at 60° head rotation (p=0.003 and p=0.013, respectively; fig 4).

Discussions

This study was conducted to determine the optimal head rotation for IJV safe catheterization using US guidance by decreasing the risk of accidental artery puncture. Systematic reviews demonstrated that the use of US, compared with anatomic landmarks, was associated with a greater procedural success, a lower number of attempts, shorter time to catheterize the vessel and a marked reduction of mechanical complications [11]. A Cochrane Database search including 22 randomized controlled trials confirmed that the rate of total complications overall and inadvertent artery puncture decreased by more than 70% when compared with US-guided insertion of IJV catheters with an anatomical landmark technique in both adults and children [8].

The anatomic variation in neck vessels plays a significant role in determining the success of IJV catheter insertion as well as the incidence of catheterization-associated complications. We observed no significant impact of head rotation on the IJV positioning relative to CCA on the right side, similar to another study that included 300 patients [12]. The right side IJV was chosen to analyze because it is associated with less CCA overlap and more lateral positioning [13]. We found that IJV shape corresponded to an ellipse in the neutral position, but the shape changed to a more circle-like form when the angle of head rotation increased. The IJV puncture angle when the head was rotated increased as compared with the neutral position, whereas the OA increased significantly at 45° and 60°. However, the IJV puncture angle was highest when the head was rotated at 30 degrees. Alterations in the IJV cross-sectional area following head rotation to the opposite side and its position relative to the CCA were also analyzed in a study involving 30 volunteers. Changes to the IJV shape with head rotation were found and IJV was the most circular at 75° head rotation measuring 2 cm above the clavicle [14].

Insertion of the IJV catheter while the head is rotated to the opposite side is an alternative to the neutral head position. Two prospective randomized studies evaluated the impact of head rotation on IJV catheterization success, comparing the neutral position and head rotation at 45°. IJV catheterization using the central landmark IJV approach in the neutral position had a lower success rate when compared with the rotated head position [15]. Meanwhile, a study of US-guided IJV catheterization did not find a significant difference in the difficulty of performing the procedure with the head placed in this position [16]. Thus, when IJV catheterization is guided with US, the neutral position could be as safe as a 45° rotation with regard to both major and minor complications.

The risk of inadvertent artery puncture during IJV catheter insertion cannot be eliminated because of the existence of the overlap between IJV and CCA. Previous studies suggested that head rotation increased the magnitude of the OA of the IJV with CCA. More than 75% overlap in the CCA by the IJV was found in 54% of 1100 patients included in the US study [17]. The probability of accidental CCA puncture could be reduced through lowering of the IJV flattening and minimizing the OA between the IJV and CCA.

The overlap of the IJV relative to the CCA increased significantly and was more notable at 45° and 60° rotation. Similarly, a trend of increasing OA with head rotation from the neutral position to 40° and 80° was found in adult volunteers [18]. In a study including infants and children, the OA of neck vessels increased significantly on both sides as the head was turned to the opposite side from the neutral position to head rotation at 90° [16]. It is important to emphasize the anatomical relationship difference in those vessels at various US probe placement levels. The higher the US probe placement was above clavicle, the bigger the OA was detected at 30° head rotation (32.6° at 4 cm and 23.6° at 2 cm, respectively) [12]. We found a larger OA at the middle level of the triangle at 30° rotation when compared with data from other study (22.9° and 14.4°, respectively) [10].

Our study had several limitations. Firstly, it was a single-center study. Secondly, the patient's height, weight or body mass index can be associated with the position and puncture angle of the IJV [10]. This correlation was not examined in our study and could be more precisely defined in further US-guided studies. Thirdly, we decided to exclude patients with known chronic heart failure because this condition determines fluid retention, higher central venous pressure, and, as a result, enlargement on IJV, which results in a difference in interpretations when compared with a sample of healthy subjects.

Conclusions

US guidance can help to increase the success of the IJV catheterization and to avoid inadvertent complications compared with the traditional anatomical landmark approach. The main obstacles to following guidelines are related to the urgency of obtaining venous access or unavailability of the US device. So, the training of the IJV catheterization using an anatomic landmark-guided approach is still important. Our data suggest that a neutral head position or excessive head rotation to the opposite side is not optimal for safe IJV catheterization. When performing right IJV catheterization in the absence of US guidance in adult patients, the head should be rotated at 30° to the left because the degree of overlap of the IJV by the CCA increases with further head rotation and can raise the risk of accidental CCA puncture.

Conflict of interest: None

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