Research Square

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Occlusive Force as a Novel Parameter for Assessing Subclavian Vein Filling: A Feasibility Study of Body, Head, and Arm Positioning

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Abstract

Background

Ultrasound-guided cannulation of the subclavian vein is a standard procedure. Venous cross-sectional area (CSA) is commonly used to assess changes in subclavian vein filling induced by patient positioning. However, CSA reflects only the geometric dimensions of the vein and does not quantify the mechanical force required for complete venous compression. We developed a simple device to measure the force required to fully compress the subclavian vein using a micro-convex ultrasound probe (occlusive force).

Methods

In this observational feasibility study, 10 healthy volunteers were examined under different body, head, and arm positions. Generalized Estimation Equations were used to analyze the influence of positioning maneuvers on occlusive force and CSA.

Results

Body and head positions showed strong effects on occlusive force. Compared to the neutral position, occlusive force increased by approximately 40% in Trendelenburg and decreased by about 20% in Anti-Trendelenburg position. Ipsilateral head rotation resulted in 20–30% higher forces, whereas contralateral rotation led to approximately 20% lower forces. Arm positioning showed inconclusive effects. CSA was similarly influenced by body and head position but with markedly smaller changes compared to occlusive force.

Conclusion

Occlusive force appears to be a sensitive parameter for detecting changes in subclavian vein filling induced by positioning maneuvers. As a novel parameter, it may complement conventional ultrasound measurements in the assessment of venous distension. Future studies are warranted to investigate its relationship with procedural success and complication rates during ultrasound-guided central venous cannulation.

Trial registration:

The study was approved by the Ethics Committee of the Saarland (Ethikkommission der Ärztekammer des Saarlandes; approval number: 234/23, 2024-02-19, study registration in the German Clinical Trials Register (DRKS00033551)).

Background

Central venous catheter (CVC) placement is a routine procedure in clinical medicine. Inserting the CVC in the subclavian vein (SCV) showed fewer infections and fewer thromboses, as well as fewer dislocations and more comfort for the patient [1], [2]. However, subclavian vein cannulation remains technically challenging. One difficulty arises from the close proximity to the pleura and the subclavian artery. Imaging the SCV using ultrasound can help to prevent complications [3], [4]. Ultrasound guided puncture techniques are recommended [5] due to their higher success rates and fewer complications [6], [7], [8].

Recently, a micro-convex ultrasound transducer with a small contact surface and a fan-shaped image has been proposed to visualize the course of the vein extending beneath the clavicle [10] and a randomized controlled trial demonstrated increased safety of an in-plane ultrasound guided puncture using this micro-convex transducer compared with the landmark technique [11].

The ease of puncturing a blood vessel is determined by its size and its filling pressure. If a vein collapses during the puncture, the needle may penetrate its posterior wall injuring adjacent structures and the puncture may go unnoticed as no blood is drawn back.

In case of poor venous filling, puncture of the SCV is recommended because in addition to its internal filling pressure it is held open by external structures. Medially, the clavicle and first rib help keep the vein open; more laterally, the pectoralis muscles and their fasciae provide additional, though lesser, support. Ultrasound-guided subclavian punctures are performed in this more lateral region where the vein is more prone to collapse because the transducer must be positioned between the needle and the clavicle. Internal and external forces combined will influence the pressure needed to compress the SCV.

Previous studies focused on changes in vessel diameter and/or cross-sectional area (CSA), to find the ideal positions of head [12], [13], arm [14], and body [15] for subclavian puncture. While CSA provides information about venous geometry, it remains unknown whether the pressure required for compression of the SCV can serve as an additional parameter.

In order to take an objective view, we developed a device capable of measuring the force transmitted via a small micro-convex ultrasound transducer required to fully occlude the SCV, which we call occlusive force. The device consists of a double cylinder encompassing the shaft of the transducer. The force is absorbed and measured between the two cylinders. Based on preliminary studies, our hypothesis is that body positioning, head rotation and arm positioning in the above order significantly influence the occlusive force. In addition, changes in the occlusive force were compared with changes in CSA to explore the relationship between both parameters under different positioning maneuvers.

Methods

After approval by the Ethics Committee of the Saarland (Ethikkommission der Ärztekammer des Saarlandes; approval number: 234/23, 2024-02-19, study registration in the German Clinical Trials

Register (DRKS00033551)), and provision of written informed consent by all participants prior to study inclusion, 10 medical student volunteers were enrolled in the study. This manuscript was prepared in accordance with the applicable STROBE guidelines.

Study design

All volunteers laid down without cushion on a flat examination table. The table consisted of a mobilization chair (Thekla® 2, Hanse Medizintechnik, Ratekau, Germany) flattened out horizontally. As a table, it can be tilted head down by 7° (Trendelenburg positioning), or head up by any degree (Anti-Trendelenburg positioning). The volunteer's body, head, and left arm (on the examination side) were positioned each in three ways: The body (B) was laid in 7°-Anti-Trendelenburg (B-A), horizontal or neutral (B-N), and in 7°-Trendelenburg position (B-T). The head (H) was rotated 30°contralaterally (H-C), hold in neutral position (H-N) or else rotated 30° ipsilaterally (H-I). The left upper arm (A) was rotated 90° internally with the thumb facing medially (A-I), hold in neutral position with the thumb facing upwards (A-N), or was rotated 90° externally with the thumb facing laterally (A-E). For the two rotations, the left elbow was slightly bent to assure that the upper arm was rotated and not the forearm. The left upper arm was always hold in 30° abduction. (Figure 1A)

All ultrasound examinations were performed by the same examiner (MB) using a micro-convex ultrasound probe (GE 8C-RS, GE-Healthcare, Düsseldorf, Germany) connected to an ultrasound machine (Vivid^{TM} iq, Version: 203, GE Healthcare) in vascular settings. The probe was positioned in the left subclavian fossa as close to the clavicle as possible (Figure 1B). The SCV was displayed in transverse view in the centre of the fan-shaped ultrasound image. All measurements were carried out at end expiration. First, with as little pressure as possible, the image was frozen, the transverse and the sagittal diameters were measured, and the cross-sectional area (CSA) was calculated. After this, the force to fully compress the SCV (occlusive force) was measured three times.

The newly developed measuring device

For these measurements, a force transducer (PCE-C-R605LF 5-H15, PCE Instruments, Meschede, Germany) connected to a force gauge (PCE-DFG N-H, PCE-Instruments), was incorporated in a double cylinder transmitting the force from the hand of the examiner to the ultrasound probe (Figure 1C). This force transmitting device was constructed as follows:

Two polyvinyl chloride pipes (PVC pressure pipes, GWT Technik, Oerlinghausen, Germany), 40 and 50 mm in diameter, were shortened to 125 and 120 mm, respectively. A slot, 10 mm wide, was cut in both pipes, 117 mm long in the thinner and 110 mm in the larger pipe. The upper ends of the pipes were closed by glueing acrylic glass discs.

Two plaster casts congruent with one half of the ultrasonic probe were produced. They were glued to acrylic glass, laid upside down on two halves of another pipe with 40 mm diameter. The interspace was filled with polyurethane foam (Montageschaum beige, Hornbach Baumarkt AG, Bornheim, Germany).

These polyurethane moulds were coated with assembly adhesive (MEM Montagekleber Extrem, MEM, Leer, Germany) to increase stability, and a slot, 10 mm wide, 30 mm long, was cut in one of them.

The two polyurethane moulds were placed around the ultrasonic probe and all were pushed into the thinner pipe. After this, the thinner pipe was fitted into the larger pipe with the force sensor in between the two acrylic disks closing the upper ends of the inner and the outer pipe. The ultrasound cable and the cable of the force sensor exited through the slots in both pipes. The head of the ultrasonic probe protruded from the inner pipe by roughly 20 mm.

Statistics

In this feasibility study we focussed on measurement methodology. For practical reasons, the number of test subjects was confined to ten. All analyses are descriptive in nature. Data were recorded on paper, then transferred to Excel (Microsoft Corp., Redmond, WA, USA) and finally to SPSS Statistics 29 (IBM, Böblingen, Germany). $p < 0,05$ was considered statistically significant. Continuous variables are expressed as mean ± standard error and categorical variables as number, unless otherwise stated.

For the primary outcome, Generalized Estimating Equations (GEE) were used with force as dependent variable and body, head and arm position as three independent factors each with one neutral and two opposing states. The same analysis was carried out with CSA as the dependent variable. In case one factor showed a significant influence, its neutral state was compared with the two other states (sequential testing). In case of significance of the model effects, the parameter estimates were considered. To compare the regression coefficients of the force measured in Newton (N) and the CSA measured in mm^2, data were standardised using z-transformation via SPSS.

We also performed Student's t-tests and Wilcoxon tests where appropriate to compare the force and likewise the CSA under different body positions, different head rotations within each body position, and different arm positions within each combination of head rotation and body position.

In addition, the influence of sex, physique (athletic versus normal physique), height and body mass index (BMI) on force and on CSA was analysed using GEE. Since all volunteers were between 21 and 27 years old, we assumed no influence of age in our study.

Results

We measured 10 healthy volunteers, 5 male and 5 female. Results were available for all positions and from all of the volunteers. (Table 1)

Influence of the participants' positioning on the occlusive force

The position of the body showed a significant influence on the force required to fully compress the SCV (GEE: $p < 0.001$), with B-A (22.5 ± 13.4 N) being smaller than B-N (29.1 ± 13.9 N, $p = 0.011$) and B-N smaller than B-T (36.6 ± 12.9 N, $p < 0.001$).

The rotation of the head also showed a significant influence (GEE: $p < 0.001$), with H-C (24.8 ± 14.3 N) being smaller than H-N (28.7 ± 14.4 N, $p < 0.001$), and H-N smaller than H-I (34.6 ± 13.3 N, $p < 0.001$).

The arm positioning also showed a significant influence (GEE: $p < 0.001$). The occlusive force during the neutral position (A-N: 26.2 ± 13.7 N) was smaller compared to A-I (31.0 ± 14.3 N, $p = 0.001$) and compared to A-E (31.0 ± 15.1 N, $p = 0.076$) although the latter comparison lacked statistical significance.

Figure 2A shows the occlusive force for every combination of body, head and arm position. Figure 3 shows the percentage change in the occlusive force for each combination of body and head position compared to the combined neutral body and head position with all arm positions averaged.

Influence of the participants' positioning on the cross-sectional-area (secondary outcome)

The CSA of the SCV was dependent on body position (GEE: $p = 0.003$) and on head rotation (GEE: $p = 0.027$), but not on the position of the arm. B-A (0.61 ± 0.26 cm^2) was not significantly different from B-N (0.65 ± 0.26 cm^2), but B-N was smaller than B-T (0.72 ± 0.24 cm^2, $p = 0.02$). H-C (0.61 ± 0.26 cm^2) was smaller than H-N (0.68 ± 0.25 cm^2; $p = 0.007$), but H-N was not significantly different from H-I (0.70 ± 0.25 cm^2).

Figure 2B shows the CSA for every combination of body, head and arm position.

Table 2 shows the relative changes of the occlusive force and the CSA of the SCV with standardized regression coefficients (GEE).

Influence of participants' characteristics

Higher forces were needed to occlude the SCV in individuals who had stated to have an athletic compared to a normal physique (36.3 ± 14.2 N vs. 24.7 ± 12.8 N; $p < 0{,}001$). These individuals also showed a higher CSA of their SCVs (0.74 ± 0.23 cm^2 versus 0.61 ± 0.26 cm^2, $p = 0.006$). Gender showed a significant influence only on the CSA (male versus female: 0.81 ± 0.26 cm^2 versus 0.51 ± 0.13 cm^2, $p = 0.018$), not on the occlusive force. No other characteristics showed any influence on the occlusive force or on the CSA.

Discussion

Sufficient venous filling is a prerequisite for good puncturing conditions. We measured the force to fully compress the subclavian vein with a newly developed device. This occlusive force was approximately 40% higher in Trendelenburg, and 20% lower in Anti-Trendelenburg compared to the horizontal position. Interestingly, ipsilateral head rotation showed 20–30% higher values whereas contralateral rotation showed roughly 20% lower values compared to the neutral head position. Arm positioning on the other hand showed inconclusive results.

It is well established that the Trendelenburg position increases the CSA of both the internal jugular and SCV and thus facilitates venous puncture. A Trendelenburg position of 5 degree shall be sufficient [16]. The SCV exhibits its maximal diameter under a moderate Trendelenburg position, with the head in a straight position and not reclined or turned contralaterally. [17] With head rotation to the ipsilateral side, a further increase in the cross-sectional area was shown [12]. In accordance with these findings, we found the occlusive force to be greater in the Trendelenburg position than in the neutral body position. This increase was observed for all arm and head positions. The greatest increase was observed in the Trendelenburg position with ipsilateral head rotation. Especially ipsilateral head rotation adds to the effect of Trendelenburg position on the occlusive force of the subclavian vein. Furthermore, ipsilateral head rotation increases the occlusive force of the SCV in horizontal body position and for arms in internal and external rotation and almost completely equalizes the decrease in occlusive force of the vein in Anti-Trendelenburg position.

With regard to arm rotation, the ideal position remains unclear. Whereas some investigators found no relevant effects for different degrees of abduction [18], others found that 90° of abduction of the upper arm combined with external rotation could improve the visualization of the vein via ultrasound. [14] We did not evaluate this position as this will lead to a distorted anatomy with a bulging pectoralis muscle making puncture of the vein more difficult. The presented data suggest that arm rotation may increase occlusive force compared with a neutral arm position, irrespective of whether internal or external rotation is applied. This may be due to the changes on the pectoralis muscles, which serve to protect the vein from external pressure. The significantly increased occlusive force of athletic volunteers might have been for the same reason.

In this study, we measured the *force* to fully compress the SCV, and applied this force via the ultrasound probe onto the skin. A determination of the *pressure* directly on the wall of the vessel would have been of greater interest, as this pressure prevents compression of the vein by the puncturing needle and thus possible puncture of the posterior wall. Obviously, this occlusive pressure is not the same as the intravascular pressure. However, exact determination of this pressure is challenging. First, the force transmitting area is not known. Since the ultrasound probe is convex, its contact surface with the skin depends on the anatomy (i.e. on the concave surface of the infraclavicular fossa) and on the exerted force. Second, the force transmission to the vein is not uniform: the force from the center of the transducer will be transmitted to the vein more strongly than the lateral forces, which are deflected laterally in a fan shape. Third, it can be assumed that part of the force exerted by the transducer is absorbed by overlying tissue and is not transmitted to the vein. Nevertheless, we assume that the

occlusive force transmitted via the ultrasound probe onto the skin correlates with the occlusive pressure onto the wall of the SCV and may provide complementary information to CSA by characterizing the mechanical behavior of the vein during external compression. Whether this translates into improved procedural success remains to be investigated.

The CSA depends on the size of the test subject, body habitus, and the individual anatomy. In fact, our data suggests a dependence on training condition and gender. However, this does not mean that the vein cannot be compressed by the advancing needle. Our data show that the CSA is less sensitive to the various positioning maneuvers than the occlusive force. One possible explanation is the nonlinear mechanical behavior of the venous wall: once stretched, it will hardly be stretched any further even by greater forces [19].

Occlusive force should not be regarded as a replacement for CSA but rather as a complementary parameter describing a different aspect of venous physiology. While CSA reflects vessel geometry, occlusive force characterizes the mechanical force required for complete venous compression. Whether this additional information provides clinical benefit remains to be determined in future studies. The present study introduces occlusive force as a novel parameter and demonstrates the feasibility and reproducibility of its measurement under different positioning conditions. These findings provide the methodological foundation for future studies evaluating the association between occlusive force and clinically relevant outcomes during ultrasound-guided central venous cannulation.

Our study has a few limitations. We only studied a small number of healthy volunteers under standardized experimental conditions. Our focus was on establishing a method to measure the force required to compress the SCV with a small micro-convex ultrasound probe which can be used for in-line puncture of the SCV. While our findings suggest occlusive force is a promising parameter, larger clinical trials are needed to validate these findings in ICU patients undergoing real CVC placement.

We acknowledge that in critically ill and possibly mechanically ventilated patients the influence of positioning maneuvers on the SCV may be different and further measurement problems may arise [15], [20]. Also, measuring the occlusive force may depend on where exactly the ultrasound probe is placed, and on its orientation. To increase the precision, all measurements were carried out by the same researcher in exactly the same manner. The force transducer will display the maximum reading after applying the force, thus pushing more than required to fully compress the vein will overestimate our primary measure. Care was taken to avoid this. All measurements were repeated three times and repeated in case of gross deviations, only the means of three valid measurements were used for further analysis.

Conclusion

Using a simple, newly constructed device, we propose a new parameter for quantification of venous filling: the force to fully compress the subclavian vein close to the clavicle with a micro-convex ultrasound probe. This occlusive force increased during Trendelenburg position as well as ipsilateral

head rotation, and decreased during Anti-Trendelenburg and contralateral head rotation. Compared to the traditional measure of the cross-sectional area, the occlusive force might be more sensitive to detect the best puncturing conditions.

Declarations

Ethics approval and consent to participate:

All procedures performed in this study involving human participants were conducted in accordance with the ethical standards of the responsible institutional and national committees on human experimentation and with the Helsinki Declaration of 1964 and its later amendments. Written informed consent to participate in the study was obtained from all participants prior to study inclusion.

The study was approved by the Ethics Committee of the Saarland (Ethikkommission der Ärztekammer des Saarlandes; approval number: 234/23, 2024-02-19, study registration in the German Clinical Trials Register (DRKS00033551)).

Consent for publication:

Informed consent was obtained from all participants prior to inclusion in the study. Written informed consent for the publication of study data and images was obtained from all participants.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that there are no competing interests.

Funding

This study was financed solely by departmental funds.

Authors' contribution

DC: This author wrote the first draft of the manuscript, helped with study design and data interpretation.

MCB: This author collected data, built the measuring device and performed data analysis.

MG: This author revised the manuscript and contributed to critical review of its intellectual content.

GW: This author helped with study design and data interpretation.

FWA: This author helped with study design and revised the manuscript

TV.: This author helped with study design and revised the manuscript

AM: This author was the driving force in study conception and design, helped with data analysis, interpreted results and helped writing the first draft of the manuscript.

All authors critically revised and approved the manuscript for submission.

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Tables

Table 1: Biometrics of participants. Data are number, or median [Minimum, Maximum]

Number of volunteers	*n*=10
Age (years)	23 [21, 27]
Sex (f/m)	5/5
Physique female	
Athletic	2
Average	3
Physique male	
Athletic	2
Average	3
Height (cm)	172 [163, 195]
BMI (kg/m^2)	22 [19, 30]

Table 2: Comparison of the relative changes of the occlusive force and the cross-sectional-area of the left subclavian vein from the neutral positions for each positioning maneuver. Generalized Estimation Equation. Pairwise comparison versus neutral was only done when the global test was significant (sequential testing).

		Occlusive Force			Cross-Sectional-Area		
		R_B	Tests of model effects	p-value	R_B	Tests of model effects	p-value
Body	B-A	-0.456	<0.001	0.011	-0.156	0.003	ns
	B-N	0		-	0		-
	B-T	0.514		<0.001	0.261		0.02
Head	H-C	-0.269	<0.001	<0.001	-0.273	0.027	0.007
	H-N	0		-	0		-
	H-I	0.402		<0.001	0.079		ns
Arm	A-I	0.331	<0.001	<0.001	0.022	ns	-
	A-N	0		-	0		-
	A-E	0.330		0.076	-0.211		-

B-A: Anti-Trendelenburg Body position; B-N: Neutral Body position; B-T: Trendelenburg Body position; H-C: Contralateral Head rotation; H-N: Neutral Head position; H-I: Ipsilateral Head rotation; A-I: Internally rotated Arm, A-N: Neutral Arm position; A-E: Externally rotated Arm.

R_B: Regression coefficient of standardized data; ns: not significant.

Figures

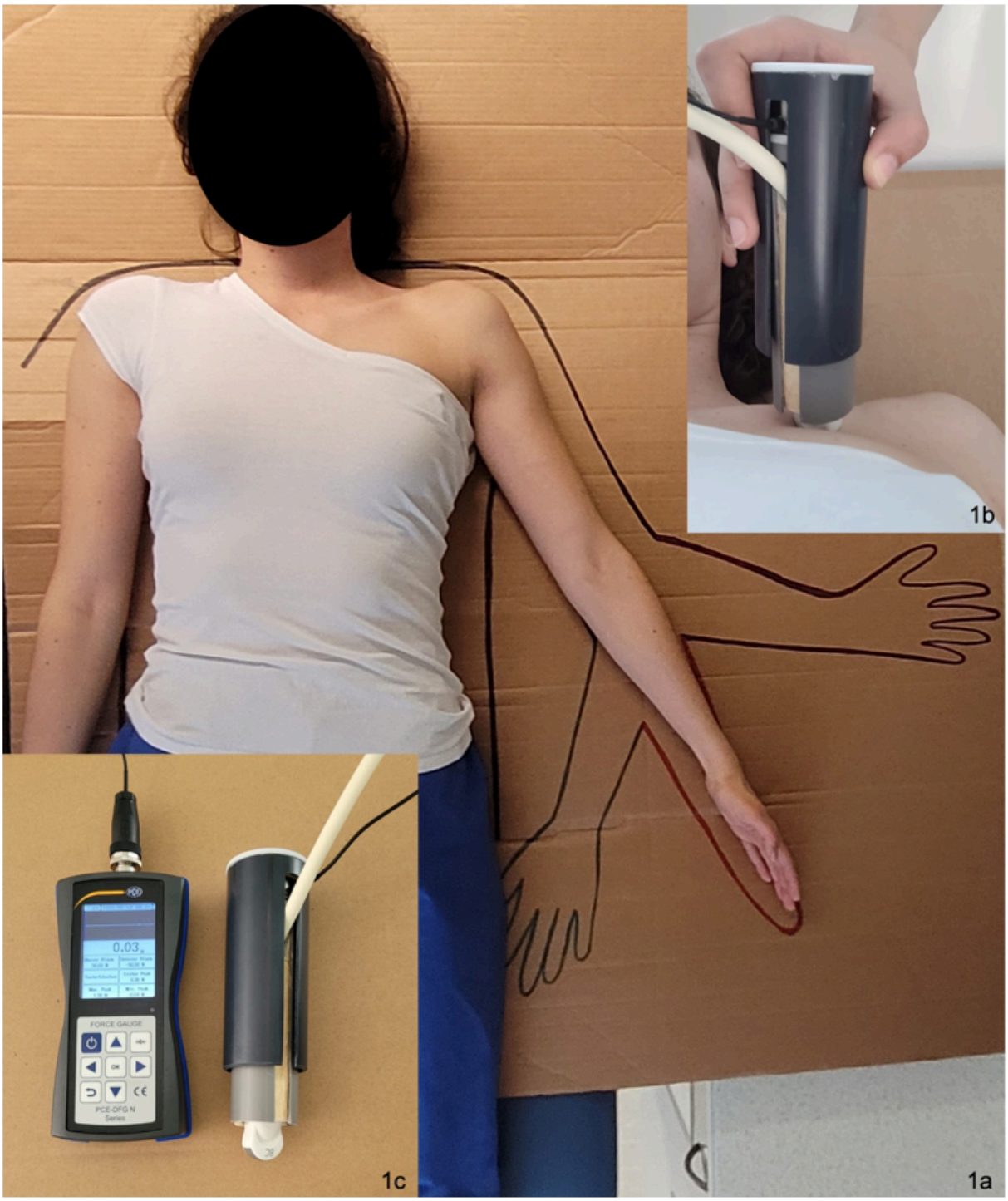
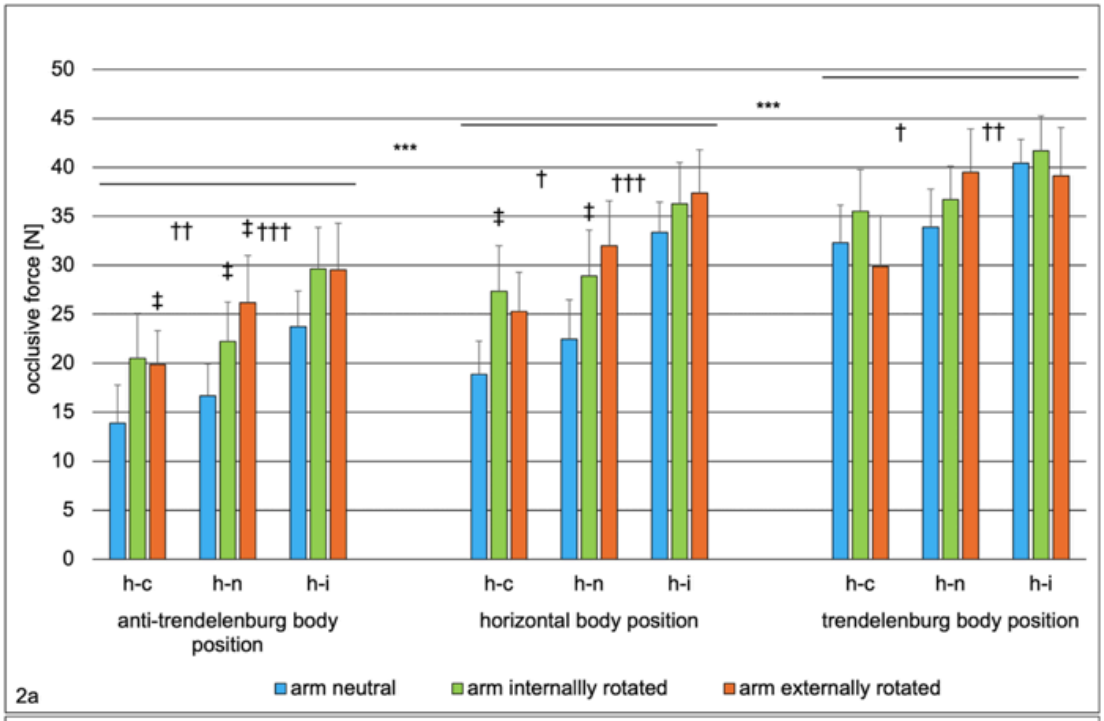


Figure 1

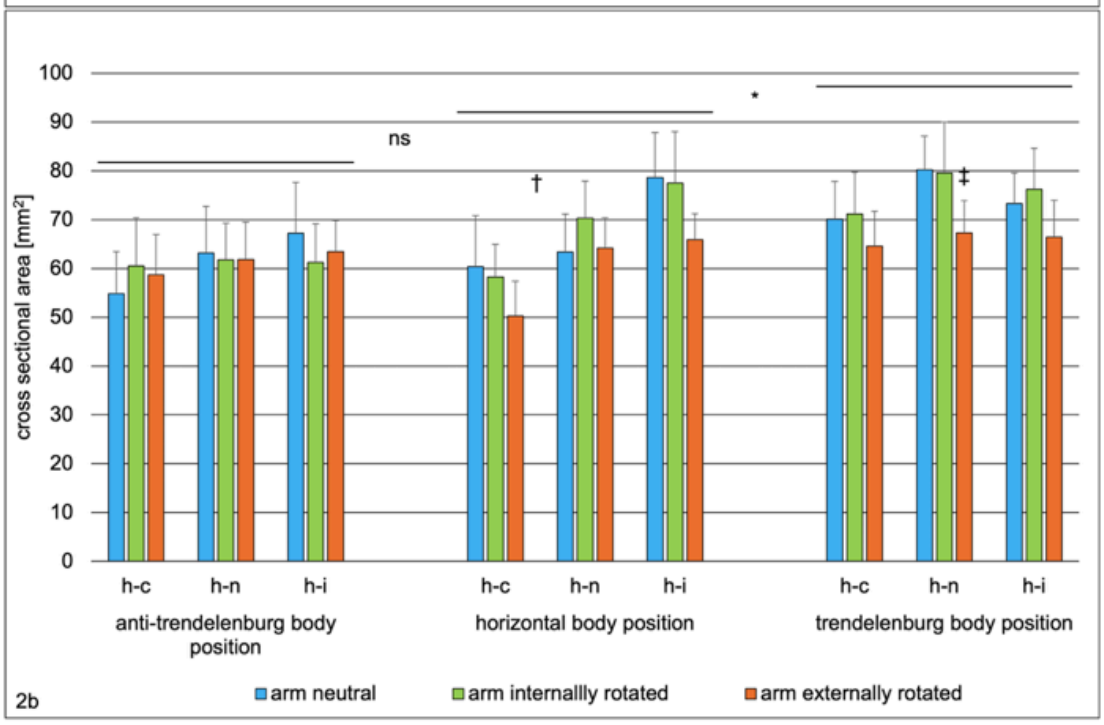
Positioning of the volunteers and measurement of the occlusive force.
a) The volunteers were lying supine on the examination table. The body, the head and the left arm were positioned each in three ways: body – anti-trendelenburg, horizontal (neutral) and trendelenburg position (not shown); head – rotated contralaterally, neutral, and rotated ipsilaterally (not shown), arm – rotated internally, neutral, and rotated externally (see cardboard markings).

b) The ultrasound transducer was positioned transversely to the subclavian vein as close to the clavicle as possible. The head of the probe protrudes by 20 mm from a double cylinder containing a force transducer between the upper ends of the inner and the outer cylinder.

c) The force transducer inside the double cylinder is connected with the force gauge via an electric cable.



2a



2b

Figure 2

Occlusive force [N] (a) and Cross-sectional-area [mm2] (b) of the subclavian vein. Mean values and standard errors are shown. h-c: Contralateral Head rotation; h-n: Neutral Head position; h-i: Ipsilateral Head rotation; blue color: neutral arm position; green color: arm internally rotated; red color: arm externally rotated.

** ($p < 0.01$), *** ($p < 0.001$): significant differences between body positions (all data for head rotations and arm positions combined). ns: not significant.

† ($p < 0.05$), †† ($p < 0.01$) and ††† ($p < 0.001$): significant differences between the different head rotations within each body position (data for all arm positions combined).

 ($p < 0.05$): significant difference of the respective arm position compared to the neutral arm position within each body position and within each head rotation.

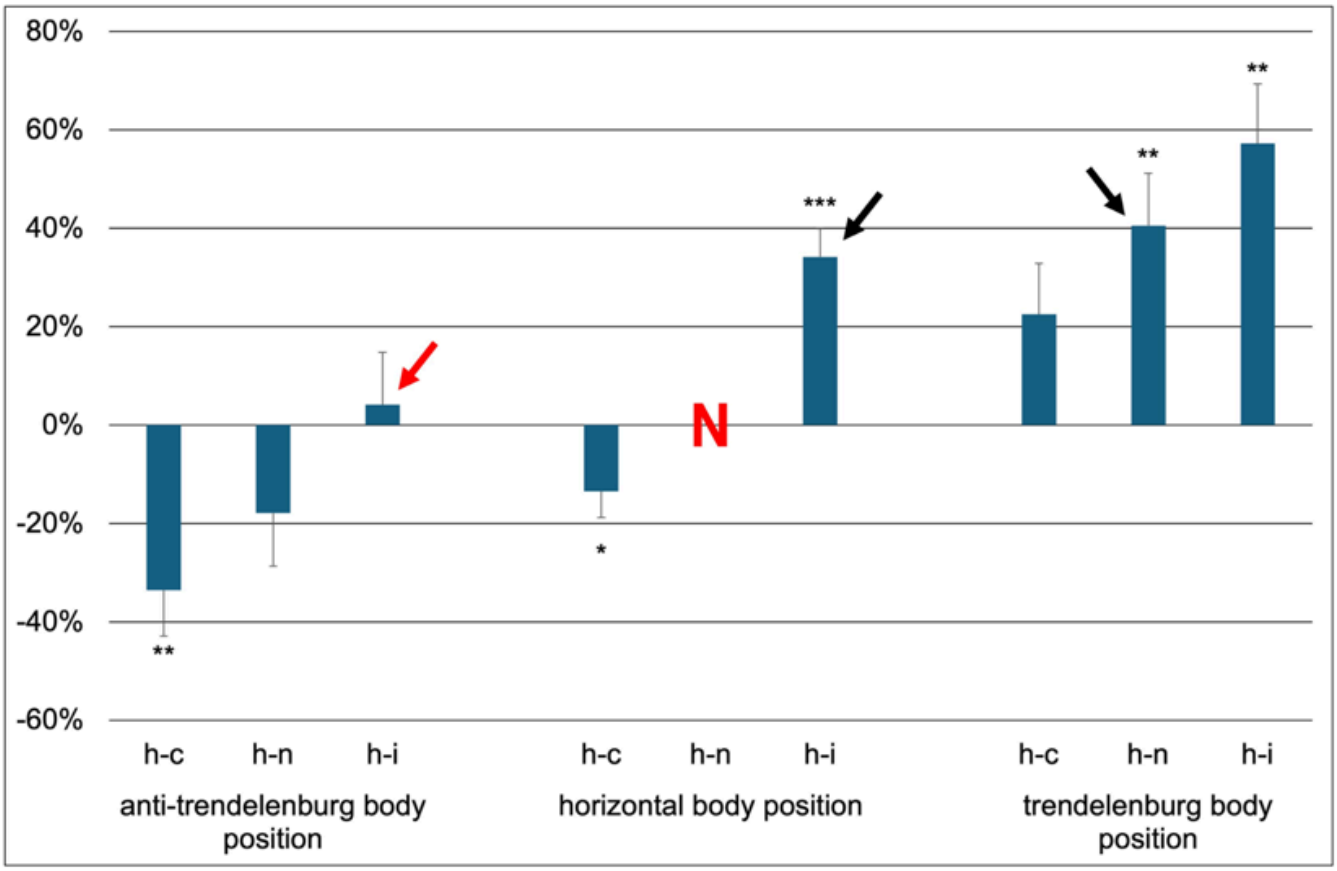


Figure 3

Changes in the occlusive force to compress the subclavian vein in comparison to the neutral head position in horizontal body position (all data for all arm positions combined). Mean values and standard errors are shown.

h-c: Contralateral Head rotation; h-n: Neutral Head position; h-i: Ipsilateral Head rotation. *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$

If a Trendelenburg body position is contraindicated, ipsilateral head rotation can provide a similarly strong effect compared to neutral head in trendelenburg position (black arrows). If in case of orthopnea even a horizontal body position is not possible, an ipsilateral head rotation (red arrow) will give rise to approximately the same occlusive pressure compared to neutral head and horizontal body positions (“N”).