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Chest radiography for simplified evaluation of central venous catheter tip positioning for safe and accurate hemodynamic monitoring – a retrospective observational study

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Abstract

Objectives: The tip-to-carina (TC) distance on simple chest X-ray (CXR) has proven value in the determination of correct central venous catheter (CVC) positioning. However, previous studies have mostly focused on preventing the atrial insertion of the CVC tip, and not on appropriate positioning for accurate hemodynamic monitoring, which is the main purpose of this invasive procedure. We aimed to assess whether the TC distance could detect the passage of the CVC tip into the superior vena cava (SVC) and the right atrium (RA), and to accordingly suggest cutoff reference values for these two aspects.

Design: Retrospective observational cohort study.

Setting: Single urban tertiary level academic hospital.

Participants: 479 patients who underwent CXR and chest computed tomography (CT) after the insertion of a CVC with a 24-hour interval during the study period.

Intervention: The TC distance was measured on CXR, and the position of the CVC tip was assessed on the chest CT images. Receiver-operating characteristics curve (ROC) analyses were conducted to ascertain the TC distance to detect SVC entrance and RA insertion of CVC tip.

Results: The TC distance could significantly detect both SVC entrance and RA insertion ($P<0.001$ for both; area under curve 0.987 and 0.965, respectively), with a reference range of −6.69 to 15.61 mm.

Conclusion: The TC distance on CXR to confirm CVC tip placement is useful for both accurate hemodynamic monitoring and prevention of fatal complications following RA insertion.

Keywords

Catheterization, Central Venous; Hemodynamic Monitoring; Vena Cava, Superior; Heart Injuries

Article summary

Strengths and limitations of this study

- This is the first study that suggested specific range of the tip-to-carina distance on simple chest X-ray to ascertain correct positioning of central venous catheter tip in extracardiac superior vena cava.
- Our study only used the data whose chest X-ray and computed tomography were taken with same posture (both arms down), which could minimize possible errors caused by migration of central venous catheter tip.
- Our results were derived from a retrospective analysis of the dataset from single center, so the generalization of the results needs to be cautiously undertaken.

Introduction

The measurement of central venous pressure (CVP) is an important monitoring criterion in intensive care, because CVP reflects the volume of blood returning to the heart, the preload, and the ability of the heart to send blood back into the arterial system. The CVP is monitored by a central venous catheter (CVC), which plays an important role in the management of critically ill patients and is usually utilized in the emergency department (ED) and intensive care units (ICU).[1 2]

The superior vena cava (SVC) is the largest central venous vein, and the CVP can be constantly measured regardless of whether the CVC tip is within the SVC or the right atrium (RA).[2] The SVC is the most suitable location to obtain CVP measurements due to the high blood flow velocity. However, if the CVC tip is inserted into RA, it can cause potentially fatal complications such as perforation, hemopericardium, and cardiac tamponade.[3-6] Therefore, the positioning of the CVC tip in the SVC such that RA insertion is prevented is important to the prevention of fatal complications while retaining the capacity for precise CVP measurements. Therefore, the lower one-third of the SVC, close to the junction of SVC and RA, is recommended as an appropriate catheter tip location.[7]

Various methods can be used to confirm the position of the CVC tip, and the gold standard is transesophageal echocardiography (TEE). However, the TEE is rarely available in clinical practice settings, except in specialist facilities that include a cardiac procedure room.[8-11] Chest X-ray (CXR) is the commonest tool to confirm the position of CVC tip because of its wide availability and relative low cost. With a CXR, the position of the CVC tip can be confirmed relative to various anatomical landmarks in the chest.[12-18] Among these, the tip-to-carina (TC) distance has been previously shown to be a reliable indicator in several studies.[11 14 17-19] However, the studies mostly focused on the prevention of intracardiac placement of the CVC tip, but not on the confirmation of appropriate positioning of the CVC tip in the SVC, which is essential for accurate hemodynamic monitoring.

This research was conducted to evaluate whether the TC distance that is measured on simple CXR is appropriate for confirming the proper placement of the CVC tip, and can prevent intracardiac placement of the CVC while retaining the ability to accurately measure the hemodynamic status. Furthermore, we aimed to ascertain reference values of the TC distance to facilitate the confirmation of appropriate placement of the CVC tip.

Material and Methods

Patient and Public Involvement

No patient involved.

Type of Study

The protocol for this retrospective observational study was reviewed and approved by the institutional ethics committee (Ethical Committee of CHA University, CHA Bundang Medical Center, approval no. 2019-11-068). The ethical body waived the need for written informed consent, and approved anonymized data collection through chart reviews in the electronic medical record (EMR) system.

Study Population and Eligibility

This study included adult patients (age ≥18 years) who visited the ED of CHA Bundang Medical Center, a tertiary-level teaching hospital with more than 85,000 yearly ED visits, between January 2, 2016 and July 2, 2018 and underwent CXR and chest computed tomography (CT) within 24 hours of CVC insertion. The exclusion criteria were: 1) age less than 18 years, 2) abnormal chest anatomy (e.g., lung cancer),[20] 3) difficultly in ascertaining the position of the CVC tip on a chest CT or CXR image, and 4) the chest CT is performed with both arms raised.[21]

Data Collection

Data on patient demographics and characteristics, including the height and the weight, were obtained through a review of the EMRs. Chest CT were conducted on a 64-slice multidetector-row CT (Light-speed VCT, GE HealthCare, Milwaukee, WI, USA) with the following scanning parameters: 120 kV, 200 mA, 0.625 mm collimation, 1.5 mm increment, 3 mm reconstruction. In addition, 60 to 120 mL ioversol (Optiray 320 mg/ml, Tyco Healthcare, Montreal, Canada) was intravenously injected, based on the patient's body mass index (BMI) (3 mL per BMI, 20 mL if BMI<20, and 120 mL if BMI>40). The scan range for the chest CT extended from the lower half of the neck to the adrenal glands, and both chest CT and CXR were conducted with the patient in the supine position with both arms down.

The presence of CVC, SVC entrance, and RA insertion of the CVC tip were verified in the chest CT and CXR images by using Picture Archiving and Communications System (PACS; Marosis, Seoul, Korea). On CT imaging, the identification of the CVC tip below the crista terminalis confirmed RA insertion, whereas tip location below the level of where both the brachiocephalic veins merge to form the SVC was defined as an entrance into the SVC.

A horizontal line perpendicular to the carina and CVC tip was drawn in the CXR image and on the CT scout image. Using the distance measurement function of PACS, the vertical distance of the two horizontal lines was measured and recorded as the TC distance. All measurements were undertaken by the same author. The carina level was defined as zero; the TC distance was described as a negative or positive number if the CVC tip was above or below the carina, respectively. The thoracic width was measured as the distance between the two points where the line perpendicular to the body axis at the level of the ceiling of the right diaphragm met the internal surface of the ribs (Figure 1). The TC distance was measured both from CXR and the scout film of the chest CT, and the distances were compared to confirm the reliability of the CXR measurement. The TC distance was divided by the BMI (body weight [kg]/height^2 [m]) and by the thoracic width to obtain body size-adjusted values.

Statistical Analysis

Data with normal distribution are presented as mean ± standard deviation (SD), and nonparametric data are presented as the median (interquartile range [IQR]). The comparison of continuous variables was undertaken with the independent t-test or the Mann–Whitney U test for data with normal or non-normal distribution respectively. The matched-pair analysis of TC distances measured from the CXR and chest CT images were undertaken with the Wilcoxon signed ranks test. We conducted receiver-operating characteristics (ROC) analysis to assess the predictive ability of the TC distance in the CXR images to ascertain the SVC entrance or RA insertion of the CVC tip, and the AUC was calculated to quantify the predictive ability. The ROC analyses were repeated with the body size-adjusted TC distance values, and their AUCs were compared with those of the TC distance values by using the DeLong test 27. The cutoff point of the TC distance to detect SVC passage of the CVC tip was defined as a value that could maximize sensitivity while maintaining 100% specificity. Similarly, the cutoff point to detect RA insertion was defined as a value that maximized specificity while maintaining 100% sensitivity. All statistical analyses were conducted in IBM SPSS Statistics 26.0 (IBM Corp., Armonk, New York, USA), except for the comparison of ROC curves for which we used R v 4.0.0 (The R Foundation for Statistical Computing, https://www.r-project.org/foundation/). Statistical significance was set to a P-value <0.05.

Results

Participant Characteristics

During the study period, a total of 758 patients met the inclusion criteria, 279 of them were excluded due, and 479 patients were included in the final analysis dataset (Figure 2). The baseline data of the study participants are described in Table 1. There was no significant difference between the TC distance measured on CXR and on the scout film of the chest CT (P=0.638).

Table 1. Baseline characteristics of the study participants

	Total	SVC entrance		*P*	RA insertion		*P*
		No (n=18)	Yes (n=461)		No (n=375)	Yes (n=104)	
Male sex	254	11, 4.3%	243, 95.7%	0.632	221, 87.0%	33, 13.0%	<0.001
Age	73 (58–80)	74.5 (55–78)	73 (58–80)	0.754	74 (61–81)	69 (52–77.5)	0.001
Height	161 (155–168)	157 (151–159)	162 (155–168)	0.037	162 (155–170)	159.5 (155–165.8)	0.074
Weight	56.0 (48.7–67.5)	58.5 (47.6–66.8)	56.0 (48.7–68.0)	0.654	55.7 (48.0–66.4)	57.1 (50.9–70.4)	0.255
BMI	21.4 (18.8–25.2)	24.6 (19.0–28.4)	21.3 (18.8–25.0)	0.181	21.1 (18.5–24.9)	22.9 (19.6–26.8)	0.034
Thoracic width	288.7 ± 22.4	289.6 ± 21.9	288.6 ± 22.4	<0.001	290.3 ± 22.3	282.8 ± 21.6	<0.001
TC distance, CXR[a]	18.6 (4.2–32.6)	−49.9 (−53.3 to −28.7)	20.0 (6.4–34.8)	<0.001	11.6 (−0.7 to 23.9)	47.0 (38.4–60.8)	<0.001
TC distance, scout[b]	18.6 (4.6–33.5)	−39.9 (−56.3 to −29.7)	20.0 (6.6–34.6)	<0.001	11.5 (0.3–23.9)	47.5 (38.7–60.3)	<0.001

Unit of the measurements: male sex (n, %), age (year), height (cm), weight (kg), thoracic width, and TC distance (mm). P-values were calculated from the Mann–Whitney U tests, except for male sex (Fischer's exact tests) and thoracic width (independent t-tests). Numerical values are described as median (interquartile range), except for male sex (n, %) and thoracic width (mean ± SD). CXR: chest X-ray; SVC: superior vena cava, RA: right atrium, TC: tip-to-carina. [a]TC distance measured on the simple chest X-ray, [b]TC distance measured on the scout film of the chest CT.

Ability of TC distance and Body size-adjusted TC Distance for Detecting SVC Entrance and RA Insertion

All TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI could significantly detect the SVC entrance of the CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI were 0.987, 0.989, and 0.992, respectively. (Figure 3A and 3B). There was no statistically significant difference in the comparisons of ROC curves of the TC distance with those of the TC distance corrected by the thoracic width as well as those of the TC distance corrected by the BMI (P=0.189 and 0.8258, respectively). The cutoff value of the TC distance to detect the SVC entrance of the CVC tip was −6.70mm (sensitivity 89.8% and specificity 100%).

All TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by the BMI could significantly detect RA insertion of eth CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by BMI were 0.966, 0.966, and 0.947, respectively (Figure 3C and 3D). There was a statistically significant difference between ROC curves of the TC distance and the TC distance corrected by the BMI. However, there was no significant difference between the ROC curves of the TC distance and the TC distance corrected by the thoracic width (P=0.995 and 0.001, respectively). The cutoff value of the TC distance to detect the RA insertion of the CVC tip was 15.62 mm (sensitivity 100% and specificity 58.93%).

Discussion

The results of the present study showed that the TC distance on the CXR is a useful parameter to confirm the appropriate positioning of the CVC tip, not only to prevent intracardiac placement that can cause serious complications, but also to ensure SVC placement for accurate CVP monitoring. Furthermore, we ascertained the optimal reference range of the TC distance based on the results.

Previous studies of methods to confirm the location of CVC tip, including those that evaluated the TC distance on simple CXR, were undertaken to only assess the ability of imaging to avoid intracardiac placement of the CVC tip.[8-19 22-25] The results of this study confirmed that the TC distance in the CXR could confirm not only extracardiac placement but also the SVC entrance of the CVC tip. The confirmation of intra-SVC placement of CVC tip is a prerequisite for accurate CVP monitoring, which is a crucial factor when considering the purpose of such an invasive procedure.

The body size-adjusted TC distance showed similar or even a significantly inferior ability to detect the SVC entrance and RA insertion of the CVC tip than the unadjusted TC distance in the present dataset. This result indicates that the body size-adjustment of the TC distance to confirm appropriate positioning of the CVC tip is not necessary.

We specified cutoff values to confirm the SVC insertion of the CVC tip as the value with maximal sensitivity and a specificity of 100%. Similarly, we specified the cutoff value for intracardiac insertion of the CVC tip as a value with maximal specificity and a sensitivity of 100%. These cutoffs were defined on the premise that it was more important to prevent false-positive than false-negative results for the determination of SVC entrance. Otherwise, the prevention of false-negative is more important than that of false-positive in the determination of intracardiac placement, with due consideration of their purposes. Thus, we obtained a range of TC distance (−6.69 to 15.61 mm) that could assure both SVC insertion and extracardiac placement of CVC tip. This range confirms the results of previous studies that suggested the carina as an anatomical landmark for the determination of CVC tip positioning based on anatomical analyses of cadavers or chest magnetic resonance imaging (MRI)/CT, given that the carina is definitely included in the cutoff range.[12 17] The carina in the CXR can be considered to be a simpler landmark, based on the results of both, the present and the previous studies, and we can ascertain safe and precise positioning of the CVC tip if the tip is located within the range of the TC distance between −6.69 and 15.61 mm.

A recent study by Dulce et al.[24] that analyzed the topographic relationships of the extrapericardial SVC by using CXR and CT imaging suggested that a location 9 mm above the carina (TC distance −9 mm) was the appropriate position for CVC tip placement, which is quite different from that of our results. We excluded the data on individuals whose chest CT images were obtained with both arms raised. However, the study of Dulce et al. mostly used the data of participants whose CT images were obtained with both arms raised. This prominent discordance may be attributable to the differences in arm position during the chest CT examination, considering that the position of the CVC tip can change when both the arms are raised.[21] The range of the TC distance determined from the present analysis could be more reliable as a reference range for the TC distance on CXR images, because the CXR is obtained with both arms downward in almost every condition.

The present study has some limitations. First, our study was a retrospective analysis of the dataset from single center, and there may be a potential bias in our results due to the incompleteness of our dataset (especially with regard to the body-size parameters) or a possible bias in the characteristics of the study participants. Therefore, the generalization of the results of this study needs to be cautiously undertaken. Second, the actual CVC tip position could be different at the time point of CXR and chest CT imaging, because of the maximum 24-hour interval between the CXR and chest CT examinations. However, the result of paired comparison of CT distances measured from both CXR and chest CT imaging in the present dataset revealed that the influence of this factor was minimal.

Conclusions

The TC distance in CXR is a simple and precise method to confirm not only the safe placement of the CVC tip but also its optimal positioning for accurate hemodynamic monitoring. The TC distances in the range of −6.69 to 15.61 mm can be used as a reference range to define cutoffs for the optimal positioning of the CVC tip.

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Competing interests statement

: The authors declare no conflict of interest.

Author contributions

: Conceptualization, Tae Nyoung Chung; Data curation, Sujin Moon; Formal analysis, Tae Nyoung Chung; Funding acquisition, Jinkun Bae; Investigation, Minwoo Kang, Jinkun Bae and Sujin Moon; Methodology, Tae Nyoung Chung; Visualization, Minwoo Kang; Writing – original draft, Minwoo Kang and Jinkun Bae; Writing – review & editing, Tae Nyoung Chung.

Data statement

: Data are available in a public, open access repository. 10.6084/m9.figshare.12403445

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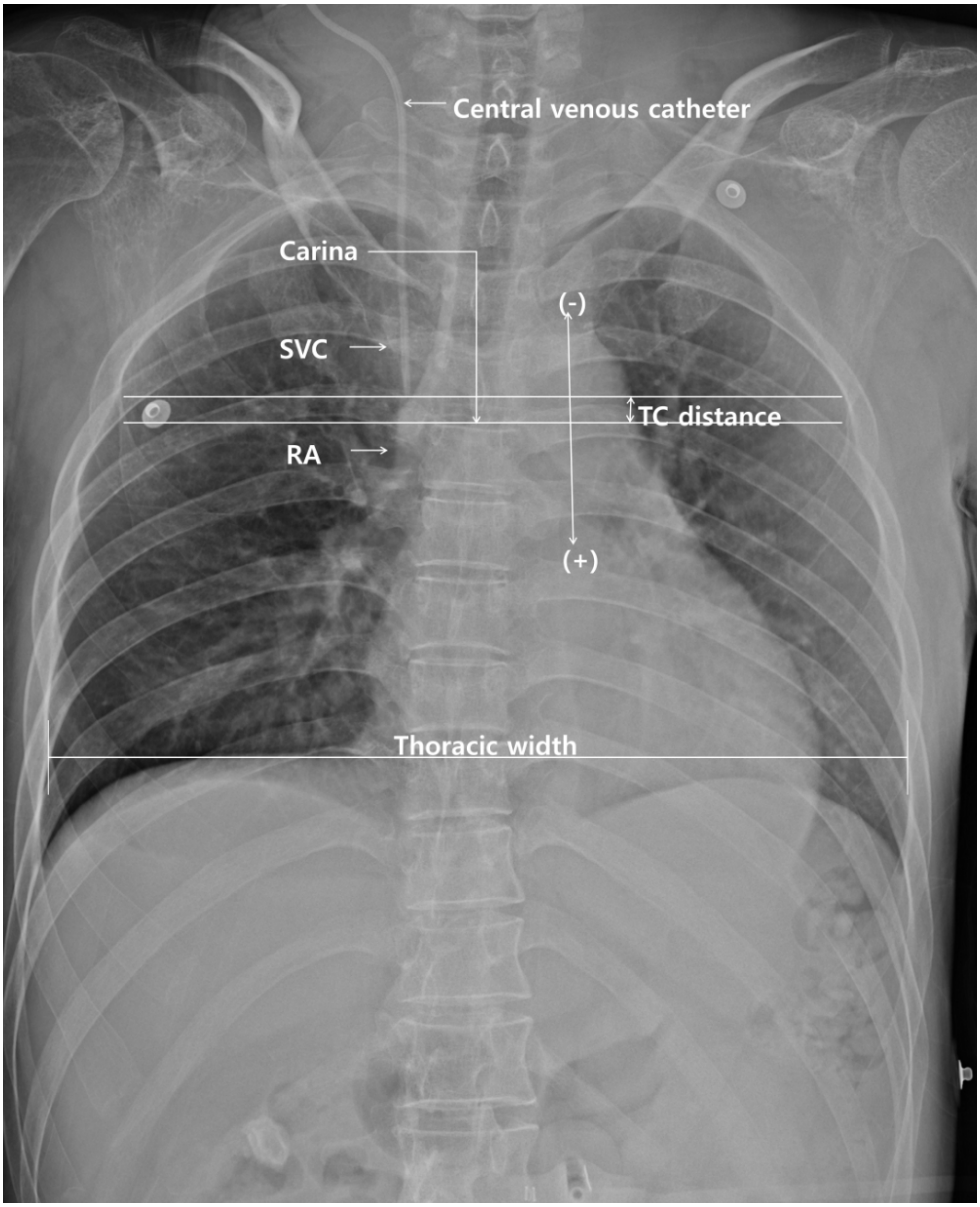
Figure legends

Figure 1. Definition of the tip-to-carina (TC) distance: Each horizontal line perpendicular to the carina and central venous catheter (CVC) tip was drawn on the simple chest X-ray image. The vertical distance of the two horizontal lines was measured and defined as the TC distance. The position in the carina is defined as zero, and positioning of the CVC tip above (-) or below (+) the carina is recorded. SVC: superior vena cava; RA: right atrium

Figure 2. Flow diagram of the patient disposition in the study. CVC: central venous catheter; CXR: simple chest X-ray; CT: computed tomography.

Figure 3. Receiver operating characteristics (ROC) curves of the tip-to-carina (TC) distance and the body size-adjusted TC distance. A) ROC curve of the TC distance to detect the passage of the central venous catheter (CVC) tip into the superior vena cava (SVC); B) comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the SVC passage of the CVC tip; C) ROC curve of the TC distance to detect the entrance of the CVC tip into the right atrium (RA); and D) the comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the RA entrance of the CVC tip.



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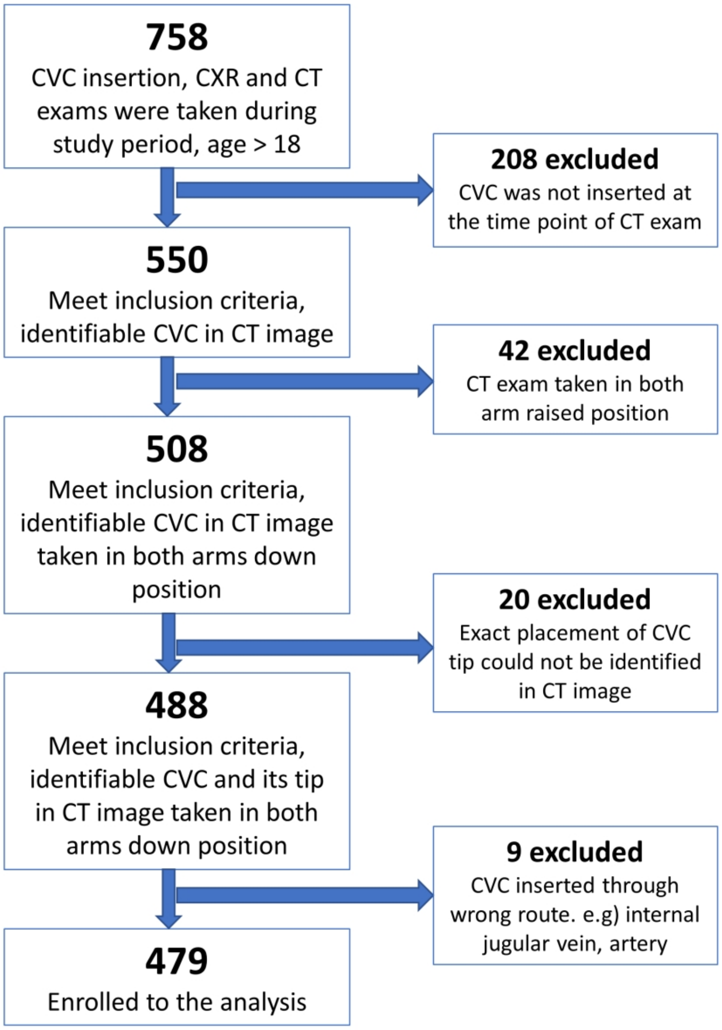

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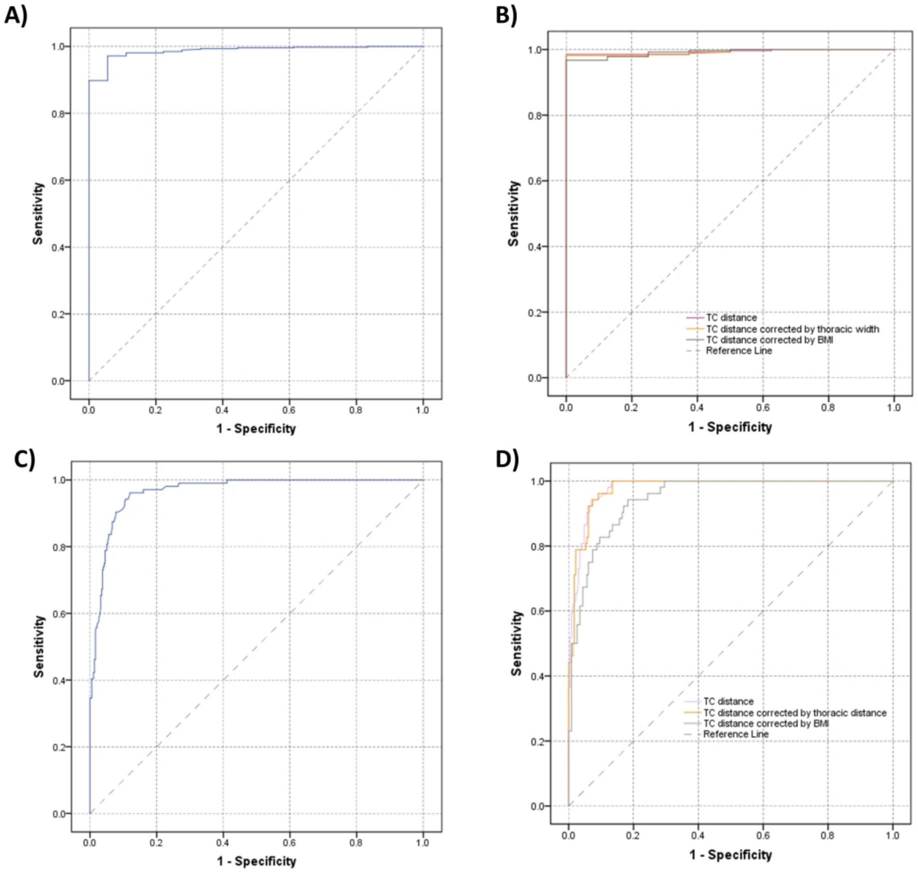

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STARD 2015

AIM

STARD stands for “Standards for Reporting Diagnostic accuracy studies”. This list of items was developed to contribute to the completeness and transparency of reporting of diagnostic accuracy studies. Authors can use the list to write informative study reports. Editors and peer-reviewers can use it to evaluate whether the information has been included in manuscripts submitted for publication.

EXPLANATION

A **diagnostic accuracy study** evaluates the ability of one or more medical tests to correctly classify study participants as having a **target condition.** This can be a disease, a disease stage, response or benefit from therapy, or an event or condition in the future. A medical test can be an imaging procedure, a laboratory test, elements from history and physical examination, a combination of these, or any other method for collecting information about the current health status of a patient.

The test whose accuracy is evaluated is called **index test.** A study can evaluate the accuracy of one or more index tests. Evaluating the ability of a medical test to correctly classify patients is typically done by comparing the distribution of the index test results with those of the **reference standard**. The reference standard is the best available method for establishing the presence or absence of the target condition. An accuracy study can rely on one or more reference standards.

If test results are categorized as either positive or negative, the cross tabulation of the index test results against those of the reference standard can be used to estimate the **sensitivity** of the index test (the proportion of participants *with* the target condition who have a positive index test), and its **specificity** (the proportion *without* the target condition who have a negative index test). From this cross tabulation (sometimes referred to as the contingency or “2x2” table), several other accuracy statistics can be estimated, such as the positive and negative **predictive values** of the test. Confidence intervals around estimates of accuracy can then be calculated to quantify the statistical **precision** of the measurements.

If the index test results can take more than two values, categorization of test results as positive or negative requires a **test positivity cut-off**. When multiple such cut-offs can be defined, authors can report a receiver operating characteristic (ROC) curve which graphically represents the combination of sensitivity and specificity for each possible test positivity cut-off. The **area under the ROC curve** informs in a single numerical value about the overall diagnostic accuracy of the index test.

The **intended use** of a medical test can be diagnosis, screening, staging, monitoring, surveillance, prediction or prognosis. The **clinical role** of a test explains its position relative to existing tests in the clinical pathway. A replacement test, for example, replaces an existing test. A triage test is used before an existing test; an add-on test is used after an existing test.

Besides diagnostic accuracy, several other outcomes and statistics may be relevant in the evaluation of medical tests. Medical tests can also be used to classify patients for purposes other than diagnosis, such as staging or prognosis. The STARD list was not explicitly developed for these other outcomes, statistics, and study types, although most STARD items would still apply.

DEVELOPMENT

This STARD list was released in 2015. The 30 items were identified by an international expert group of methodologists, researchers, and editors. The guiding principle in the development of STARD was to select items that, when reported, would help readers to judge the potential for bias in the study, to appraise the applicability of the study findings and the validity of conclusions and recommendations. The list represents an update of the first version, which was published in 2003.

More information can be found on http://www.equator-network.org/reporting-guidelines/stard.

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Chest radiography for simplified evaluation of central venous catheter tip positioning for safe and accurate hemodynamic monitoring – a retrospective observational study

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Abstract

Objectives: The tip-to-carina (TC) distance on simple chest X-ray (CXR) has proven value in the determination of correct central venous catheter (CVC) positioning. However, previous studies have mostly focused on preventing the atrial insertion of the CVC tip, and not on appropriate positioning for accurate hemodynamic monitoring, which is the main purpose of this invasive procedure. We aimed to assess whether the TC distance could detect the passage of the CVC tip into the superior vena cava (SVC) and the right atrium (RA), and to accordingly suggest cutoff reference values for these two aspects.

Design: Retrospective observational cohort study.

Setting: Single urban tertiary level academic hospital.

Participants: 479 patients who underwent CXR and chest computed tomography (CT) after the insertion of a CVC with a 24-hour interval during the study period.

Intervention: The TC distance was measured on CXR, and the position of the CVC tip was assessed on the chest CT images. Receiver-operating characteristics curve (ROC) analyses were conducted to ascertain the TC distance to detect SVC entrance and RA insertion of CVC tip.

Results: The TC distance could significantly detect both SVC entrance and RA insertion ($P<0.001$ for both; area under curve 0.987 and 0.965, respectively), with a reference range of −6.69 to 15.61 mm.

Conclusion: The TC distance on CXR to confirm CVC tip placement is useful for both accurate hemodynamic monitoring and prevention of fatal complications following RA insertion.

Keywords

Catheterization, Central Venous; Hemodynamic Monitoring; Vena Cava, Superior; Heart Injuries

Article summary

Strengths and limitations of this study

- This is the first study that suggested specific range of the tip-to-carina distance on simple chest X-ray to ascertain correct positioning of central venous catheter tip in extracardiac superior vena cava.
- Our study only used the data whose chest X-ray and computed tomography were taken with same posture (both arms down), which could minimize possible errors caused by migration of central venous catheter tip.
- Our results were derived from a retrospective analysis of the dataset from single center, so the generalization of the results needs to be cautiously undertaken.

Introduction

Central venous catheter (CVC) insertion is a widely performed procedure that plays an important role in the care of critically ill patients, as well as patients who require parenteral nutrition, antibiotic therapy, chemotherapy, hemodialysis and patients with difficult peripheral venous access.[1] Central venous pressure (CVP), which is measured by CVC, is also the most frequently used hemodynamic parameter for fluid therapy of critically ill patients.[2]

The superior vena cava (SVC) is the largest central vein, and the CVP can be constantly measured regardless of whether the CVC tip is within the SVC or the right atrium (RA).[3] The SVC is the most suitable location to obtain CVP measurements due to the high blood flow velocity. However, if the CVC tip is inserted into RA, it may cause potentially fatal complications such as perforation, hemopericardium, and cardiac tamponade.[4-7] Therefore, the positioning of the CVC tip in the SVC such that RA insertion is prevented may be necessary for the prevention of possible fatal complications while retaining the capacity for precise CVP measurements. The lower one-third of the SVC, close to the junction of SVC and RA, is recommended as an appropriate catheter tip location.[8]

Various methods can be used to confirm the position of the CVC tip, and the gold standard is transesophageal echocardiography (TEE). However, the TEE is rarely available in clinical practice settings, except in specialist facilities that include a cardiac procedure room.[9-12] Chest X-ray (CXR) is the commonest tool to confirm the position of CVC tip because of its wide availability and relative low cost. Recently, point-of-care ultrasound has shown its value in the confirmation of CVC tip placement, and even showed superiority in many aspects compared with CXR.[13-15] However, sole use of ultrasound in real practice is restricted by various factors, and CXR is still used in almost every case of CVC tip placement.[16] With a CXR, the position of the CVC tip can be confirmed relative to various anatomical landmarks in the chest.[17-23] Among these, the tip-to-carina (TC) distance has been previously shown to be a reliable indicator in several studies.[19 22-24] However, the studies mostly focused on the prevention of intracardiac placement of the CVC tip, but not on the confirmation of appropriate positioning of the CVC tip in the SVC, which is essential for accurate hemodynamic monitoring.

This research was conducted to evaluate whether the TC distance that is measured on simple CXR is appropriate for confirming the proper placement of the CVC tip, and can prevent intracardiac placement of the CVC while retaining the ability to accurately measure the hemodynamic status. Furthermore, we aimed to ascertain reference

values of the TC distance to facilitate the confirmation of appropriate placement of the CVC tip.

Material and Methods

Patient and Public Involvement

No patient involved.

Type of Study

The protocol for this retrospective observational study was reviewed and approved by the institutional ethics committee (Ethical Committee of CHA University, CHA Bundang Medical Center, approval no. 2019-11-068). The ethical body waived the need for written informed consent, and approved anonymized data collection through chart reviews in the electronic medical record (EMR) system.

Study Population and Eligibility

This study included adult patients (age ≥18 years) who visited the ED of CHA Bundang Medical Center, a tertiary-level teaching hospital with more than 85,000 yearly emergency department (ED) visits, between January 2, 2016 and July 2, 2018 and underwent CXR and chest computed tomography (CT) within 24 hours of CVC insertion. The exclusion criteria were: 1) age less than 18 years, 2) abnormal chest anatomy (e.g., lung cancer),[25] 3) difficultly in ascertaining the position of the CVC tip on a chest CT or CXR image, and 4) the chest CT is performed with both arms raised.[26]

Data Collection

Data on patient demographics and characteristics, including the height and the weight, were obtained through a review of the EMRs. Chest CT were conducted on a 64-slice multidetector-row CT (Light-speed VCT, GE HealthCare, Milwaukee, WI, USA) with the following scanning parameters: 120 kV, 200 mA, 0.625 mm collimation, 1.5 mm increment, 3 mm reconstruction. In addition, 60 to 120 mL ioversol (Optiray 320 mg/ml, Tyco Healthcare, Montreal, Canada) was intravenously injected, based on the patient's body mass index (BMI) (3 mL per BMI, 20 mL if BMI<20, and 120 mL if BMI>40). The scan range for the chest CT extended from the lower half of the neck to the adrenal glands, and both chest CT and CXR were conducted with the patient in the supine position with both arms down.

The presence of CVC, SVC entrance, and RA insertion of the CVC tip were verified in the chest CT and CXR images by using Picture Archiving and Communications System (PACS; Marosis, Seoul, Korea). The decision was made based on the agreement of two separate researchers. On CT imaging, the identification of the CVC tip below the crista terminalis confirmed RA insertion, whereas tip location below the level of where both the brachiocephalic veins merge to form the SVC was defined as an entrance into the SVC.

A horizontal line perpendicular to the carina and CVC tip was drawn in the CXR image and on the CT scout image. Using the distance measurement function of PACS, the vertical distance of the two horizontal lines was measured and recorded as the TC distance. All TC distance measurements were undertaken by the same author. The carina level was defined as zero; the TC distance was described as a negative or positive number if the CVC tip was above or below the carina, respectively. The thoracic width was measured as the distance between the two points where the line perpendicular to the body axis at the level of the ceiling of the right diaphragm met the internal surface of the ribs (Figure 1). The TC distance was measured both from CXR and the scout film of the chest CT, and the distances were compared to confirm the reliability of the CXR measurement. The TC distance was divided by the BMI (body weight [kg]/height^2 [m]) and by the thoracic width to obtain body size-adjusted values.

Outcomes

This study was to evaluate the diagnostic ability of TC distance measured on CXR for the confirmation of the proper positioning of CVC tip, and to suggest corresponding reference range, using chest CT as a reference standard. Primary outcomes were the detection of SVC entrance and RA insertion, and secondary outcome was the relative predictive ability of body size-adjusted TC distance to assess the necessity of body size-adjustment.

Statistical Analysis

Data with normal distribution are presented as mean ± standard deviation (SD), and nonparametric data are presented as the median (interquartile range [IQR]). The comparison of continuous variables was undertaken with the independent t-test or the Mann–Whitney U test for data with normal or non-normal distribution respectively. The matched-pair analysis of TC distances measured from the CXR and chest CT images were undertaken with the Wilcoxon signed ranks test. We conducted receiver-operating characteristics (ROC) analysis to assess the predictive ability of the TC distance in the CXR images to ascertain the SVC entrance or RA insertion of the CVC tip, and the AUC was calculated to quantify the predictive ability. The ROC analyses were repeated with the body size-adjusted TC distance values, and their AUCs were compared with those of the TC distance values by using the DeLong test.[27] The cutoff point of the TC distance to detect SVC passage of the CVC tip was defined as a value that could maximize sensitivity while maintaining 100% specificity. Similarly, the cutoff point to detect RA insertion was defined as a value that maximized specificity while maintaining 100% sensitivity. All statistical analyses were conducted in IBM SPSS Statistics 26.0 (IBM Corp., Armonk, New York, USA), except for the comparison of ROC curves for which we used R v 4.0.0 (The R Foundation for Statistical Computing, https://www.r-project.org/foundation/). Statistical significance was set to a P-value <0.05.

Results

Participant Characteristics

During the study period, a total of 758 patients met the inclusion criteria, 279 of them were excluded due, and 479 patients were included in the final analysis dataset (Figure 2). The baseline data of the study participants are described in Table 1. There was no significant difference between the TC distance measured on CXR and on the scout film of the chest CT (P=0.638).

Table 1. Baseline characteristics of the study participants

		Total	SVC entrance		*P*	RA insertion		*P*
			No (n=18)	Yes (n=461)		No (n=375)	Yes (n=104)	
Male sex		254	11, 4.3%	243, 95.7%	0.632	221, 87.0%	33, 13.0%	<0.001
Age		73 (58–80)	74.5 (55–78)	73 (58–80)	0.754	74 (61–81)	69 (52–77.5)	0.001
Height		161 (155–168)	157 (151–159)	162 (155–168)	0.037	162 (155–170)	159.5 (155–165.8)	0.074
Weight		56.0 (48.7–67.5)	58.5 (47.6–66.8)	56.0 (48.7–68.0)	0.654	55.7 (48.0–66.4)	57.1 (50.9–70.4)	0.255
BMI		21.4 (18.8–25.2)	24.6 (19.0–28.4)	21.3 (18.8–25.0)	0.181	21.1 (18.5–24.9)	22.9 (19.6–26.8)	0.034
Access	IJV	101	10, 9.9%	91, 90.1%	0.001	93, 92.1%	8, 7.9%	<0.001
	SCV	378	8, 2.1%	370, 97.9%		282, 74.6%	96, 25.4%	
Thoracic width		288.7 ± 22.4	289.6 ± 21.9	288.6 ± 22.4	<0.001	290.3 ± 22.3	282.8 ± 21.6	<0.001
TC distance, CXR[a]		18.6 (4.2–32.6)	−49.9 (−53.3 to −28.7)	20.0 (6.4–34.8)	<0.001	11.6 (−0.7 to 23.9)	47.0 (38.4–60.8)	<0.001
TC distance, scout[b]		18.6 (4.6–33.5)	−39.9 (−56.3 to −29.7)	20.0 (6.6–34.6)	<0.001	11.5 (0.3–23.9)	47.5 (38.7–60.3)	<0.001

Unit of the measurements: male sex (n, %), age (year), height (cm), weight (kg), thoracic width, and TC distance (mm). P-values were calculated from the Mann–Whitney U tests, except for male sex (Fischer's exact tests) and thoracic width (independent t-tests). Numerical values are described as median (interquartile range), except for male sex (n, %), access (n, %), and thoracic width (mean ± SD). CXR: chest X-ray; SVC: superior vena cava, RA: right atrium, IJV: internal jugular vein, SCV: subclavian vein, TC: tip-to-carina. [a]TC distance measured on the simple chest X-ray, [b]TC distance measured on the scout film of the chest CT.

Ability of TC distance and Body size-adjusted TC Distance for Detecting SVC Entrance and RA Insertion

All TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI could significantly detect the SVC entrance of the CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI were 0.987, 0.989, and 0.992, respectively. (Figure 3A and 3B). There was no statistically significant difference in the comparisons of ROC curves of the TC distance with those of the TC distance corrected by the thoracic width as well as those of the TC distance corrected by the BMI (P=0.189 and 0.8258, respectively). The cutoff value of the TC distance to detect the SVC entrance of the CVC tip was −6.70mm (sensitivity 89.8% and specificity 100%).

All TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by the BMI could significantly detect RA insertion of eth CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by BMI were 0.966, 0.966, and 0.947, respectively (Figure 3C and 3D). There was a statistically significant difference between ROC curves of the TC distance and the TC distance corrected by the BMI. However, there was no significant difference between the ROC curves of the TC distance and the TC distance corrected by the thoracic width (P=0.995 and 0.001, respectively). The cutoff value of the TC distance to detect the RA insertion of the CVC tip was 15.62 mm (sensitivity 100% and specificity 58.93%).

Discussion

The results of the present study showed that the TC distance on the CXR is a useful parameter to confirm the appropriate positioning of the CVC tip, not only to prevent intracardiac placement that can cause serious complications, but also to ensure SVC placement for accurate CVP monitoring. Furthermore, we ascertained the optimal reference range of the TC distance based on the results.

Previous studies of methods to confirm the location of CVC tip, including those that evaluated the TC distance on simple CXR, were undertaken to only assess the ability of imaging to avoid intracardiac placement of the CVC tip.[9-12 17-24 28-31] The results of this study confirmed that the TC distance in the CXR could confirm not only extracardiac placement but also the SVC entrance of the CVC tip. The confirmation of intra-SVC placement of CVC tip is a prerequisite for accurate CVP monitoring, which is a crucial factor when considering the purpose of such an invasive procedure.

The results of recent clinical trials suggest that CVP may not be a reliable index for assessing fluid responsiveness, and the use of CVP for such a purpose is not recommended in the most of clinical guidelines any more, despite its widespread utilization.[32 33] Moreover, intracardiac placement of CVC is not that dangerous as was before, owing to the development of the material.[34] These facts may devalue the precise confirmation of CVC tip placement. However, CVP measurement still has some valuable aspects, and, most of all, it is still the most frequently used hemodynamic variable for deciding when to start fluid administration during critical care.[35] Furthermore, it may be unethical to take an unnecessary risk even if it is minimal. Hence, the positioning of CVC tip in an appropriate place is still important as long as CVP insertion is performed.

The body size-adjusted TC distance showed similar or even a significantly inferior ability to detect the SVC entrance and RA insertion of the CVC tip than the unadjusted TC distance in the present dataset. This result indicates that the body size-adjustment of the TC distance to confirm appropriate positioning of the CVC tip is not necessary.

We specified cutoff values to confirm the SVC insertion of the CVC tip as the value with maximal sensitivity and a specificity of 100%. Similarly, we specified the cutoff value for intracardiac insertion of the CVC tip as a

value with maximal specificity and a sensitivity of 100%. These cutoffs were defined on the premise that it was more important to prevent false-positive than false-negative results for the determination of SVC entrance. Otherwise, the prevention of false-negative is more important than that of false-positive in the determination of intracardiac placement, with due consideration of their purposes. Thus, we obtained a range of TC distance (−6.69 to 15.61 mm) that could assure both SVC insertion and extracardiac placement of CVC tip. One may think that the cutoff value to detect intracardiac insertion can cause critical error in practice, because significantly high false-positive rate is expected. However, what we have to do in the case that TC distance exceed the cutoff value indicating intracardiac insertion is just a simple moving backward of CVC tip within the suggested range of TC distance. Hence, the proper positioning of CVC tip can be easily maintained even in the case of false detection of intracardiac insertion. This range also confirms the results of previous studies that suggested the carina as an anatomical landmark for the determination of CVC tip positioning based on anatomical analyses of cadavers or chest magnetic resonance imaging (MRI)/CT, given that the carina is definitely included in the cutoff range.[17 22] The carina in the CXR can be considered to be a simpler landmark, based on the results of both, the present and the previous studies, and we can ascertain safe and precise positioning of the CVC tip if the tip is located within the range of the TC distance between −6.69 and 15.61 mm.

A recent study by Dulce et al.[30] that analyzed the topographic relationships of the extrapericardial SVC by using CXR and CT imaging suggested that a location 9 mm above the carina (TC distance −9 mm) was the appropriate position for CVC tip placement, which is quite different from that of our results. We excluded the data on individuals whose chest CT images were obtained with both arms raised. However, the study of Dulce et al. mostly used the data of participants whose CT images were obtained with both arms raised. This prominent discordance may be attributable to the differences in arm position during the chest CT examination, considering that the position of the CVC tip can change when both the arms are raised.[26] The range of the TC distance determined from the present analysis could be more reliable as a reference range for the TC distance on CXR images, because the CXR is obtained with both arms downward in almost every condition.

The present study has some limitations. First, our study was a retrospective analysis of the dataset from single center, and there may be a potential bias in our results due to the incompleteness of our dataset (especially with regard to the body-size parameters) or a possible bias in the characteristics of the study participants. Therefore, the generalization of the results of this study needs to be cautiously undertaken. Second, the actual CVC tip

position could be different at the time point of CXR and chest CT imaging, because of the maximum 24-hour interval between the CXR and chest CT examinations. However, the result of paired comparison of CT distances measured from both CXR and chest CT imaging in the present dataset revealed that the influence of this factor was minimal. Nevertheless, there could still be a chance of significant CVC tip migration, considering that even the respiratory phases could affect CVC tip position.[36]

Conclusions

The TC distance in CXR is a simple and precise method to confirm not only the safe placement of the CVC tip but also its optimal positioning for accurate hemodynamic monitoring. The TC distances in the range of −6.69 to 15.61 mm can be used as a reference range to define cutoffs for the optimal positioning of the CVC tip.

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Competing interests statement

: The authors declare no conflict of interest.

Author contributions

: Conceptualization, Tae Nyoung Chung; Data curation, Sujin Moon; Formal analysis, Tae Nyoung Chung; Funding acquisition, Jinkun Bae; Investigation, Minwoo Kang, Jinkun Bae and Sujin Moon; Methodology, Tae Nyoung Chung; Visualization, Minwoo Kang; Writing – original draft, Minwoo Kang and Jinkun Bae; Writing – review & editing, Tae Nyoung Chung.

Data statement

: Data are available in a public, open access repository. 10.6084/m9.figshare.12403445

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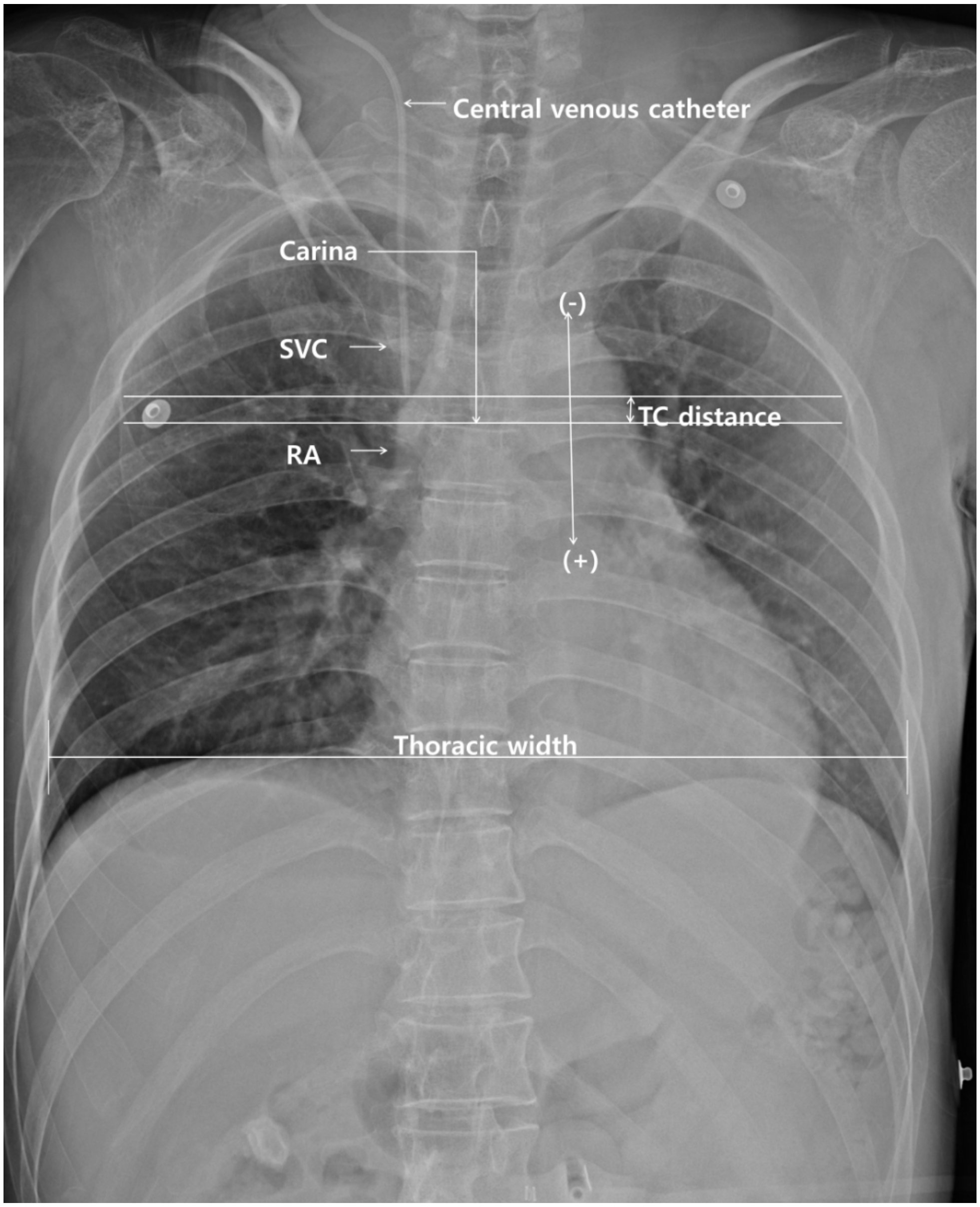
Figure legends

Figure 1. Definition of the tip-to-carina (TC) distance: Each horizontal line perpendicular to the carina and central venous catheter (CVC) tip was drawn on the simple chest X-ray image. The vertical distance of the two horizontal lines was measured and defined as the TC distance. The position in the carina is defined as zero, and positioning of the CVC tip above (-) or below (+) the carina is recorded. SVC: superior vena cava; RA: right atrium

Figure 2. Flow diagram of the patient disposition in the study. CVC: central venous catheter; CXR: simple chest X-ray; CT: computed tomography.

Figure 3. Receiver operating characteristics (ROC) curves of the tip-to-carina (TC) distance and the body size-adjusted TC distance. A) ROC curve of the TC distance to detect the passage of the central venous catheter (CVC) tip into the superior vena cava (SVC); B) comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the SVC passage of the CVC tip; C) ROC curve of the TC distance to detect the entrance of the CVC tip into the right atrium (RA); and D) the comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the RA entrance of the CVC tip.



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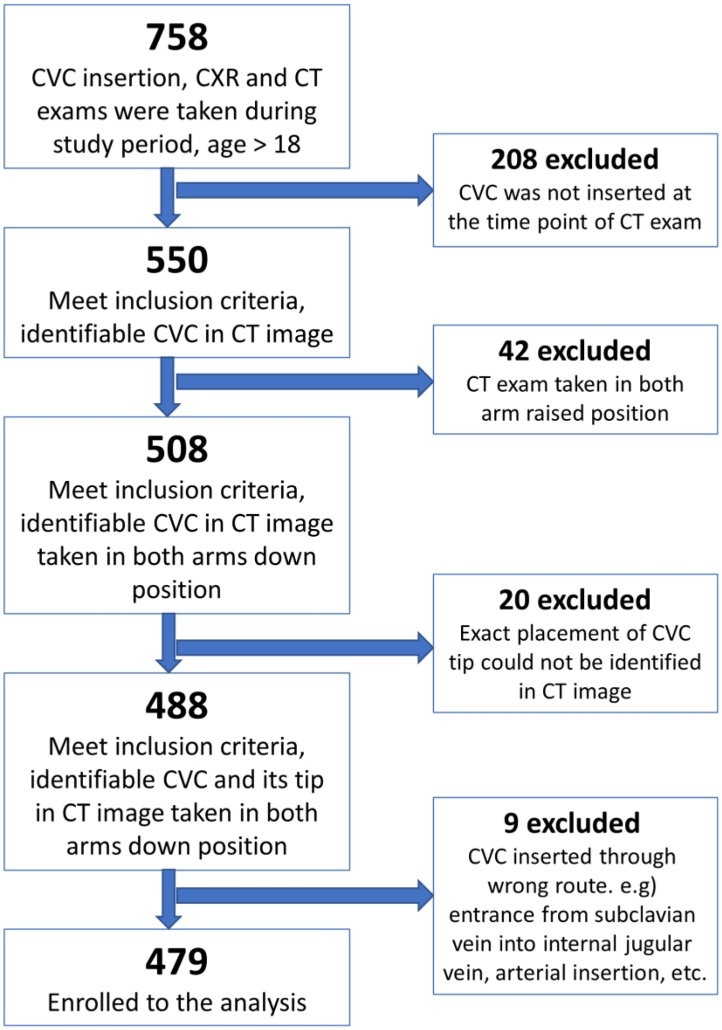

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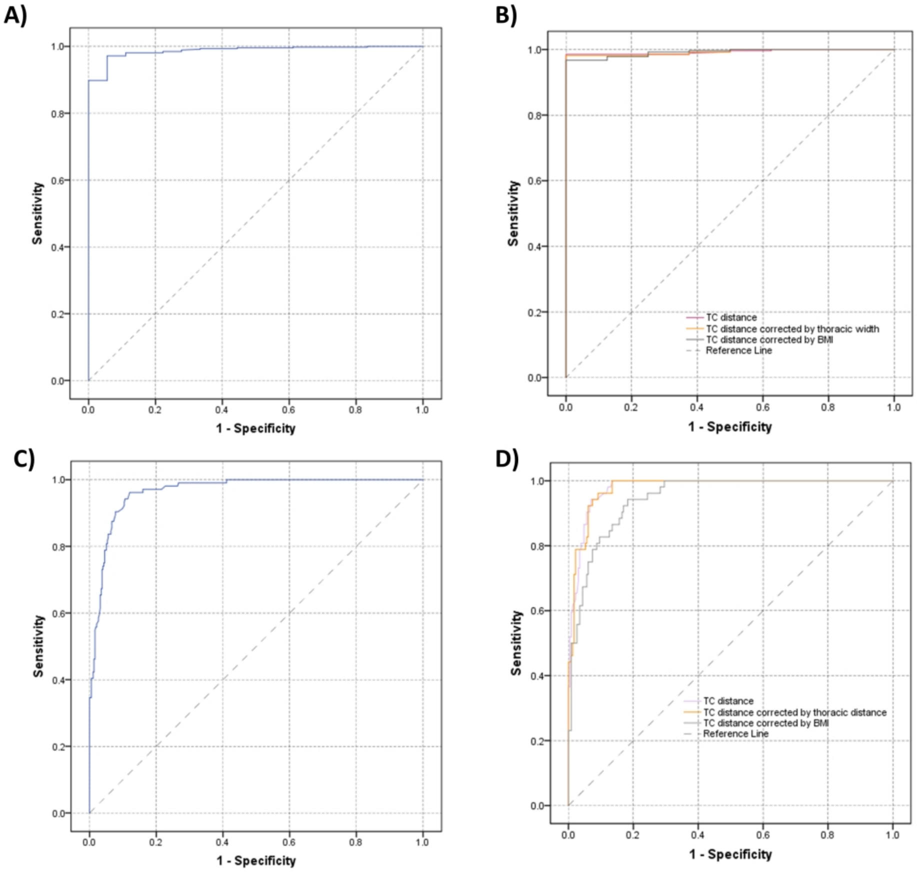

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240x219mm (300 x 300 DPI)

Section & Topic	No	Item	Reported on page #
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	2	Structured summary of study design, methods, results, and conclusions (for specific guidance, see STARD for Abstracts)	2
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	3	Scientific and clinical background, including the intended use and clinical role of the index test	4
	4	Study objectives and hypotheses	4
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Study design	**5**	Whether data collection was planned before the index test and reference standard were performed (prospective study) or after (retrospective study)	5
Participants	**6**	Eligibility criteria	5
	7	On what basis potentially eligible participants were identified (such as symptoms, results from previous tests, inclusion in registry)	5
	8	Where and when potentially eligible participants were identified (setting, location and dates)	5
	9	Whether participants formed a consecutive, random or convenience series	5
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	11	Rationale for choosing the reference standard (if alternatives exist)	4
	12a	Definition of and rationale for test positivity cut-offs or result categories of the index test, distinguishing pre-specified from exploratory	9
	12b	Definition of and rationale for test positivity cut-offs or result categories of the reference standard, distinguishing pre-specified from exploratory	
	13a	Whether clinical information and reference standard results were available to the performers/readers of the index test	7
	13b	Whether clinical information and index test results were available to the assessors of the reference standard	
Analysis	**14**	Methods for estimating or comparing measures of diagnostic accuracy	6
	15	How indeterminate index test or reference standard results were handled	6
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	17	Any analyses of variability in diagnostic accuracy, distinguishing pre-specified from exploratory	6
	18	Intended sample size and how it was determined	
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Test results	**23**	Cross tabulation of the index test results (or their distribution) by the results of the reference standard	7
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DISCUSSION			
	26	Study limitations, including sources of potential bias, statistical uncertainty, and generalisability	10
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	30	Sources of funding and other support; role of funders	11

STARD 2015

AIM

STARD stands for “Standards for Reporting Diagnostic accuracy studies”. This list of items was developed to contribute to the completeness and transparency of reporting of diagnostic accuracy studies. Authors can use the list to write informative study reports. Editors and peer-reviewers can use it to evaluate whether the information has been included in manuscripts submitted for publication.

EXPLANATION

A **diagnostic accuracy study** evaluates the ability of one or more medical tests to correctly classify study participants as having a **target condition.** This can be a disease, a disease stage, response or benefit from therapy, or an event or condition in the future. A medical test can be an imaging procedure, a laboratory test, elements from history and physical examination, a combination of these, or any other method for collecting information about the current health status of a patient.

The test whose accuracy is evaluated is called **index test.** A study can evaluate the accuracy of one or more index tests. Evaluating the ability of a medical test to correctly classify patients is typically done by comparing the distribution of the index test results with those of the **reference standard**. The reference standard is the best available method for establishing the presence or absence of the target condition. An accuracy study can rely on one or more reference standards.

If test results are categorized as either positive or negative, the cross tabulation of the index test results against those of the reference standard can be used to estimate the **sensitivity** of the index test (the proportion of participants *with* the target condition who have a positive index test), and its **specificity** (the proportion *without* the target condition who have a negative index test). From this cross tabulation (sometimes referred to as the contingency or “2x2” table), several other accuracy statistics can be estimated, such as the positive and negative **predictive values** of the test. Confidence intervals around estimates of accuracy can then be calculated to quantify the statistical **precision** of the measurements.

If the index test results can take more than two values, categorization of test results as positive or negative requires a **test positivity cut-off**. When multiple such cut-offs can be defined, authors can report a receiver operating characteristic (ROC) curve which graphically represents the combination of sensitivity and specificity for each possible test positivity cut-off. The **area under the ROC curve** informs in a single numerical value about the overall diagnostic accuracy of the index test.

The **intended use** of a medical test can be diagnosis, screening, staging, monitoring, surveillance, prediction or prognosis. The **clinical role** of a test explains its position relative to existing tests in the clinical pathway. A replacement test, for example, replaces an existing test. A triage test is used before an existing test; an add-on test is used after an existing test.

Besides diagnostic accuracy, several other outcomes and statistics may be relevant in the evaluation of medical tests. Medical tests can also be used to classify patients for purposes other than diagnosis, such as staging or prognosis. The STARD list was not explicitly developed for these other outcomes, statistics, and study types, although most STARD items would still apply.

DEVELOPMENT

This STARD list was released in 2015. The 30 items were identified by an international expert group of methodologists, researchers, and editors. The guiding principle in the development of STARD was to select items that, when reported, would help readers to judge the potential for bias in the study, to appraise the applicability of the study findings and the validity of conclusions and recommendations. The list represents an update of the first version, which was published in 2003.

More information can be found on [http://www.equator-network.org/reporting-guidelines/stard.](http://www.equator-network.org/reporting-guidelines/stard)

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Chest radiography for simplified evaluation of central venous catheter tip positioning for safe and accurate hemodynamic monitoring – a retrospective observational study

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Chest radiography for simplified evaluation of central venous catheter tip positioning for safe and accurate hemodynamic monitoring – a retrospective observational study

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Abstract

Objectives: The tip-to-carina (TC) distance on simple chest X-ray (CXR) has proven value in the determination of correct central venous catheter (CVC) positioning. However, previous studies have mostly focused on preventing the atrial insertion of the CVC tip, and not on appropriate positioning for accurate hemodynamic monitoring. We aimed to assess whether the TC distance could detect the passage of the CVC tip into the superior vena cava (SVC) and the right atrium (RA), and to accordingly suggest cutoff reference values for these two aspects.

Design: Retrospective observational cohort study.

Setting: Single urban tertiary level academic hospital.

Participants: 479 patients who underwent CXR and chest computed tomography (CT) after the insertion of a CVC with a 24-hour interval during the study period.

Intervention: The TC distance was measured on CXR, and the position of the CVC tip was assessed on the chest CT images. The TC distance was described as a negative or positive number if the CVC tip was above or below the carina, respectively. Receiver-operating characteristics curve (ROC) analyses were conducted to ascertain the TC distance to detect SVC entrance and RA insertion of CVC tip.

Results: The TC distance could significantly detect both SVC entrance and RA insertion ($P<0.001$ for both; area under curve 0.987 and 0.965, respectively), with a reference range of −6.69 to 15.61 mm.

Conclusion: The TC distance in CXR is a simple and precise method to confirm not only the safe placement of the CVC tip but also its optimal positioning for accurate hemodynamic monitoring.

Keywords

Catheterization, Central Venous; Hemodynamic Monitoring; Vena Cava, Superior; Heart Injuries

Article summary

Strengths and limitations of this study

- This is the first study that suggested specific range of the tip-to-carina distance on simple chest X-ray to ascertain correct positioning of central venous catheter tip in extracardiac superior vena cava.
- Our study only used the data whose chest X-ray and computed tomography were taken with same posture (both arms down), which could minimize possible errors caused by migration of central venous catheter tip.
- Our results were derived from a retrospective analysis of the dataset from single center, so the generalization of the results needs to be cautiously undertaken.

Introduction

Central venous catheter (CVC) insertion is a widely performed procedure that plays an important role in the care of critically ill patients, as well as patients who require parenteral nutrition, antibiotic therapy, chemotherapy, hemodialysis and patients with difficult peripheral venous access.[1] Central venous pressure (CVP), which is measured by CVC, is also the most frequently used hemodynamic parameter for fluid therapy of critically ill patients.[2]

The superior vena cava (SVC) is the largest central vein, and the CVP can be constantly measured regardless of whether the CVC tip is within the SVC or the right atrium (RA).[3] The SVC is the most suitable location to obtain CVP measurements due to the high blood flow velocity. However, if the CVC tip is inserted into RA, it may cause potentially fatal complications such as perforation, hemopericardium, and cardiac tamponade.[4-7] Therefore, the positioning of the CVC tip in the SVC such that RA insertion is prevented may be necessary for the prevention of possible fatal complications while retaining the capacity for precise CVP measurements. The lower one-third of the SVC, close to the junction of SVC and RA, is recommended as an appropriate catheter tip location.[8]

Various methods can be used to confirm the position of the CVC tip, and the gold standard is transesophageal echocardiography (TEE). However, the TEE is rarely available in clinical practice settings, except in specialist facilities that include a cardiac procedure room.[9-12] Chest X-ray (CXR) is the commonest tool to confirm the position of CVC tip because of its wide availability and relative low cost. Recently, point-of-care ultrasound has shown its value in the confirmation of CVC tip placement, and even showed superiority in many aspects compared with CXR.[13-15] However, sole use of ultrasound in real practice is restricted by various factors, and CXR is still used in almost every case of CVC tip placement.[16] With a CXR, the position of the CVC tip can be confirmed relative to various anatomical landmarks in the chest.[17-23] Among these, the tip-to-carina (TC) distance has been previously shown to be a reliable indicator in several studies.[19 22-24] However, the studies mostly focused on the prevention of intracardiac placement of the CVC tip, but not on the confirmation of appropriate positioning of the CVC tip in the SVC, which is essential for accurate hemodynamic monitoring.

We hypothesized that the TC distance that is measured on simple CXR is appropriate for confirming the proper placement of the CVC tip, and can prevent intracardiac placement of the CVC while retaining the ability to accurately measure the hemodynamic status. We aimed to evaluate this hypothesis, and to ascertain reference

values of the TC distance to facilitate the confirmation of appropriate placement of the CVC tip.

Material and Methods

Patient and Public Involvement

No patient involved.

Type of Study

The protocol for this retrospective observational study was reviewed and approved by the institutional ethics committee (Ethical Committee of CHA University, CHA Bundang Medical Center, approval no. 2019-11-068). The ethical body waived the need for written informed consent, and approved anonymized data collection through chart reviews in the electronic medical record (EMR) system.

Study Population and Eligibility

This study included adult patients (age ≥18 years) who visited the ED of CHA Bundang Medical Center, a tertiary-level teaching hospital with more than 85,000 yearly emergency department (ED) visits, between January 2, 2016 and July 2, 2018 and underwent CXR and chest computed tomography (CT) within 24 hours of CVC insertion. The exclusion criteria were: 1) age less than 18 years, 2) abnormal chest anatomy (e.g., lung cancer),[25] 3) difficultly in ascertaining the position of the CVC tip on a chest CT or CXR image, and 4) the chest CT is performed with both arms raised.[26]

Data Collection

Data on patient demographics and characteristics, including the height and the weight, were obtained through a review of the EMRs. Chest CT were conducted on a 64-slice multidetector-row CT (Light-speed VCT, GE HealthCare, Milwaukee, WI, USA) with the following scanning parameters: 120 kV, 200 mA, 0.625 mm collimation, 1.5 mm increment, 3 mm reconstruction. In addition, 60 to 120 mL ioversol (Optiray 320 mg/ml, Tyco Healthcare, Montreal, Canada) was intravenously injected, based on the patient's body mass index (BMI) (3 mL per BMI, 20 mL if BMI<20, and 120 mL if BMI>40). The scan range for the chest CT extended from the lower half of the neck to the adrenal glands, and both chest CT and CXR were conducted with the patient in the supine position with both arms down.

The presence of CVC, SVC entrance, and RA insertion of the CVC tip were verified in the chest CT and CXR images by using Picture Archiving and Communications System (PACS; Marosis, Seoul, Korea). The decision was made based on the agreement of two separate researchers. On CT imaging, the identification of the CVC tip below the crista terminalis confirmed RA insertion, whereas tip location below the level of where both the brachiocephalic veins merge to form the SVC was defined as an entrance into the SVC.

A horizontal line perpendicular to the carina and CVC tip was drawn in the CXR image and on the CT scout image. Using the distance measurement function of PACS, the vertical distance of the two horizontal lines was measured and recorded as the TC distance. All TC distance measurements were undertaken by the same author. The carina level was defined as zero; the TC distance was described as a negative or positive number if the CVC tip was above or below the carina, respectively. The thoracic width was measured as the distance between the two points where the line perpendicular to the body axis at the level of the ceiling of the right diaphragm met the internal surface of the ribs (Figure 1). The TC distance was measured both from CXR and the scout film of the chest CT, and the distances were compared to confirm the reliability of the CXR measurement. The TC distance was divided by the BMI (body weight [kg]/height^2 [m]) and by the thoracic width to obtain body size-adjusted values.

Outcomes

This study was to evaluate the diagnostic ability of TC distance measured on CXR for the confirmation of the proper positioning of CVC tip, and to suggest corresponding reference range, using chest CT as a reference standard. Primary outcomes were the detection of SVC entrance and RA insertion, and secondary outcome was the relative predictive ability of body size-adjusted TC distance to assess the necessity of body size-adjustment.

Statistical Analysis

Data with normal distribution are presented as mean ± standard deviation (SD), and nonparametric data are presented as the median (interquartile range [IQR]). The comparison of continuous variables was undertaken with the independent t-test or the Mann–Whitney U test for data with normal or non-normal distribution respectively. The matched-pair analysis of TC distances measured from the CXR and chest CT images were undertaken with the Wilcoxon signed ranks test. We conducted receiver-operating characteristics (ROC) analysis to assess the predictive ability of the TC distance in the CXR images to ascertain the SVC entrance or RA insertion of the CVC tip, and the AUC was calculated to quantify the predictive ability. The ROC analyses were repeated with the body size-adjusted TC distance values, and their AUCs were compared with those of the TC distance values by using the DeLong test.[27] The cutoff point of the TC distance to detect SVC passage of the CVC tip was defined as a value that could maximize sensitivity while maintaining 100% specificity. Similarly, the cutoff point to detect RA insertion was defined as a value that maximized specificity while maintaining 100% sensitivity. All statistical analyses were conducted in IBM SPSS Statistics 26.0 (IBM Corp., Armonk, New York, USA), except for the comparison of ROC curves for which we used R v 4.0.0 (The R Foundation for Statistical Computing, https://www.r-project.org/foundation/). Statistical significance was set to a P-value <0.05.

Results

Participant Characteristics

During the study period, a total of 758 patients met the inclusion criteria, 279 of them were excluded due, and 479 patients were included in the final analysis dataset (Figure 2). The baseline data of the study participants are described in Table 1. There was no significant difference between the TC distance measured on CXR and on the scout film of the chest CT (P=0.638).

Table 1. Baseline characteristics of the study participants

		Total	SVC entrance		RA insertion	
			No (n=18)	Yes (n=461)	No (n=375)	Yes (n=104)
Male sex		254	11, 4.3%	243, 95.7%	221, 87.0%	33, 13.0%
Age		73 (58–80)	74.5 (55–78)	73 (58–80)	74 (61–81)	69 (52–77.5)
Height		161 (155–168)	157 (151–159)	162 (155–168)	162 (155–170)	159.5 (155–165.8)
Weight		56.0 (48.7–67.5)	58.5 (47.6–66.8)	56.0 (48.7–68.0)	55.7 (48.0–66.4)	57.1 (50.9–70.4)
BMI		21.4 (18.8–25.2)	24.6 (19.0–28.4)	21.3 (18.8–25.0)	21.1 (18.5–24.9)	22.9 (19.6–26.8)
Access	IJV	101	10, 9.9%	91, 90.1%	93, 92.1%	8, 7.9%
	SCV	378	8, 2.1%	370, 97.9%	282, 74.6%	96, 25.4%
Thoracic width		288.7 ± 22.4	289.6 ± 21.9	288.6 ± 22.4	290.3 ± 22.3	282.8 ± 21.6
TC distance, CXR[a]		18.6 (4.2–32.6)	−49.9 (−53.3 to −28.7)	20.0 (6.4–34.8)	11.6 (−0.7 to 23.9)	47.0 (38.4–60.8)
TC distance, scout[b]		18.6 (4.6–33.5)	−39.9 (−56.3 to −29.7)	20.0 (6.6–34.6)	11.5 (0.3–23.9)	47.5 (38.7–60.3)

Unit of the measurements: male sex (n, %), age (year), height (cm), weight (kg), access (n, %), thoracic width (mm), and TC distance (mm). Numerical values are described as median (interquartile range), except for male sex (n, %), access (n, %), and thoracic width (mean ± SD). CXR: chest X-ray; SVC: superior vena cava, RA: right atrium, IJV: internal jugular vein, SCV: subclavian vein, TC: tip-to-carina. [a]TC distance measured on the simple chest X-ray, [b]TC distance measured on the scout film of the chest CT.

Ability of TC distance and Body size-adjusted TC Distance for Detecting SVC Entrance and RA Insertion

All TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI could significantly detect the SVC entrance of the CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI were 0.987, 0.989, and 0.992, respectively. (Figure 3A and 3B). There was no statistically significant difference in the comparisons of ROC curves of the TC distance with those of the TC distance corrected by the thoracic width as well as those of the TC distance corrected by the BMI (P=0.189 and 0.8258, respectively). The cutoff value of the TC distance to detect the SVC entrance of the CVC tip was −6.70mm (sensitivity 89.8% and specificity 100%).

All TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by the BMI could significantly detect RA insertion of eth CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by BMI were 0.966, 0.966, and 0.947, respectively (Figure 3C and 3D). There was a statistically significant difference between ROC curves of the TC distance and the TC distance corrected by the BMI. However, there was no significant difference between the ROC curves of the TC distance and the TC distance corrected by the thoracic width (P=0.995 and 0.001, respectively). The cutoff value of the TC distance to detect the RA insertion of the CVC tip was 15.62 mm (sensitivity 100% and specificity 58.93%).

Discussion

The results of the present study showed that the TC distance on the CXR is a useful parameter to confirm the appropriate positioning of the CVC tip, not only to prevent intracardiac placement that can cause serious complications, but also to ensure SVC placement for accurate CVP monitoring. Furthermore, we ascertained the optimal reference range of the TC distance based on the results.

Previous studies of methods to confirm the location of CVC tip, including those that evaluated the TC distance on simple CXR, were undertaken to only assess the ability of imaging to avoid intracardiac placement of the CVC tip.[9-12 17-24 28-31] The results of this study confirmed that the TC distance in the CXR could confirm not only extracardiac placement but also the SVC entrance of the CVC tip. The confirmation of intra-SVC placement of CVC tip is a prerequisite for accurate CVP monitoring, which is a crucial factor when considering the purpose of such an invasive procedure.

The results of recent clinical trials suggest that CVP may not be a reliable index for assessing fluid responsiveness, and the use of CVP for such a purpose is not recommended in the most of clinical guidelines any more, despite its widespread utilization.[32 33] Moreover, intracardiac placement of CVC is not that dangerous as was before, owing to the development of the material.[34] These facts may devalue the precise confirmation of CVC tip placement. However, CVP measurement still has some valuable aspects, and, most of all, it is still the most frequently used hemodynamic variable for deciding when to start fluid administration during critical care.[35] Furthermore, it may be unethical to take an unnecessary risk even if it is minimal. Hence, the positioning of CVC tip in an appropriate place is still important as long as CVP insertion is performed.

The body size-adjusted TC distance showed similar or even a significantly inferior ability to detect the SVC entrance and RA insertion of the CVC tip than the unadjusted TC distance in the present dataset. This result indicates that the body size-adjustment of the TC distance to confirm appropriate positioning of the CVC tip is not necessary.

We specified cutoff values to confirm the SVC insertion of the CVC tip as the value with maximal sensitivity and a specificity of 100%. Similarly, we specified the cutoff value for intracardiac insertion of the CVC tip as a

value with maximal specificity and a sensitivity of 100%. These cutoffs were defined on the premise that it was more important to prevent false-positive than false-negative results for the determination of SVC entrance. Otherwise, the prevention of false-negative is more important than that of false-positive in the determination of intracardiac placement, with due consideration of their purposes. Thus, we obtained a range of TC distance (−6.69 to 15.61 mm) that could assure both SVC insertion and extracardiac placement of CVC tip. One may think that the cutoff value to detect intracardiac insertion can cause critical error in practice, because significantly high false-positive rate is expected. However, what we have to do in the case that TC distance exceed the cutoff value indicating intracardiac insertion is just a simple moving backward of CVC tip within the suggested range of TC distance. Hence, the proper positioning of CVC tip can be easily maintained even in the case of false detection of intracardiac insertion. This range also confirms the results of previous studies that suggested the carina as an anatomical landmark for the determination of CVC tip positioning based on anatomical analyses of cadavers or chest magnetic resonance imaging (MRI)/CT, given that the carina is definitely included in the cutoff range.[17 22] The carina in the CXR can be considered to be a simpler landmark, based on the results of both, the present and the previous studies, and we can ascertain safe and precise positioning of the CVC tip if the tip is located within the range of the TC distance between −6.69 and 15.61 mm.

A recent study by Dulce et al.[30] that analyzed the topographic relationships of the extrapericardial SVC by using CXR and CT imaging suggested that a location 9 mm above the carina (TC distance −9 mm) was the appropriate position for CVC tip placement, which is quite different from that of our results. We excluded the data on individuals whose chest CT images were obtained with both arms raised. However, the study of Dulce et al. mostly used the data of participants whose CT images were obtained with both arms raised. This prominent discordance may be attributable to the differences in arm position during the chest CT examination, considering that the position of the CVC tip can change when both the arms are raised.[26] The range of the TC distance determined from the present analysis could be more reliable as a reference range for the TC distance on CXR images, because the CXR is obtained with both arms downward in almost every condition.

The present study has some limitations. First, our study was a retrospective analysis of the dataset from single center, and there may be a potential bias in our results due to the incompleteness of our dataset (especially with regard to the body-size parameters) or a possible bias in the characteristics of the study participants. Therefore, the generalization of the results of this study needs to be cautiously undertaken. Second, the actual CVC tip

position could be different at the time point of CXR and chest CT imaging, because of the maximum 24-hour interval between the CXR and chest CT examinations. However, the result of paired comparison of CT distances measured from both CXR and chest CT imaging in the present dataset revealed that the influence of this factor was minimal. Nevertheless, there could still be a chance of significant CVC tip migration, considering that even the respiratory phases could affect CVC tip position.[36] Third, we excluded some cases during data collection because of the difficultly in ascertaining the position of the CVC tip on a chest CT image, and this could cause a selection bias although we made every effort not to exclude a case intentionally. The exclusion was carefully decided only when two independent researchers agreed that CVC tip was unidentifiable due to poor image quality or being obscured by contrast media.

Conclusions

The TC distance in CXR is a simple and precise method to confirm not only the safe placement of the CVC tip but also its optimal positioning for accurate hemodynamic monitoring. The TC distances in the range of −6.69 to 15.61 mm can be used as a reference range to define cutoffs for the optimal positioning of the CVC tip.

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Competing interests statement

: The authors declare no conflict of interest.

Author contributions

: Conceptualization, Tae Nyoung Chung; Data curation, Sujin Moon; Formal analysis, Tae Nyoung Chung; Funding acquisition, Jinkun Bae; Investigation, Minwoo Kang, Jinkun Bae and Sujin Moon; Methodology, Tae Nyoung Chung; Visualization, Minwoo Kang; Writing – original draft, Minwoo Kang and Jinkun Bae; Writing – review & editing, Tae Nyoung Chung.

Data statement

: Data are available in a public, open access repository. 10.6084/m9.figshare.12403445

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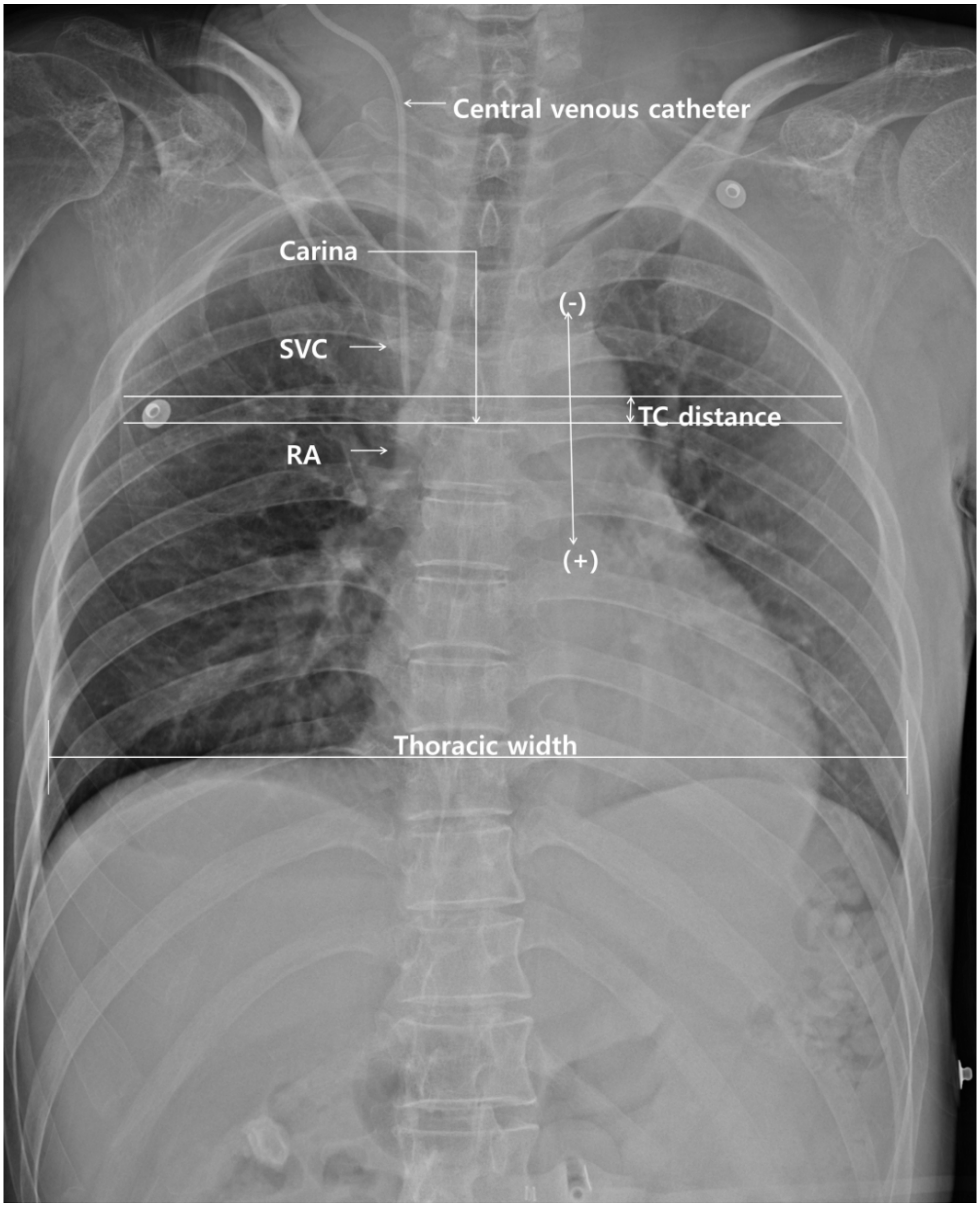
Figure legends

Figure 1. Definition of the tip-to-carina (TC) distance: Each horizontal line perpendicular to the carina and central venous catheter (CVC) tip was drawn on the simple chest X-ray image. The vertical distance of the two horizontal lines was measured and defined as the TC distance. The position in the carina is defined as zero, and positioning of the CVC tip above (-) or below (+) the carina is recorded. SVC: superior vena cava; RA: right atrium

Figure 2. Flow diagram of the patient disposition in the study. CVC: central venous catheter; CXR: simple chest X-ray; CT: computed tomography.

Figure 3. Receiver operating characteristics (ROC) curves of the tip-to-carina (TC) distance and the body size-adjusted TC distance. A) ROC curve of the TC distance to detect the passage of the central venous catheter (CVC) tip into the superior vena cava (SVC); B) comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the SVC passage of the CVC tip; C) ROC curve of the TC distance to detect the entrance of the CVC tip into the right atrium (RA); and D) the comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the RA entrance of the CVC tip.



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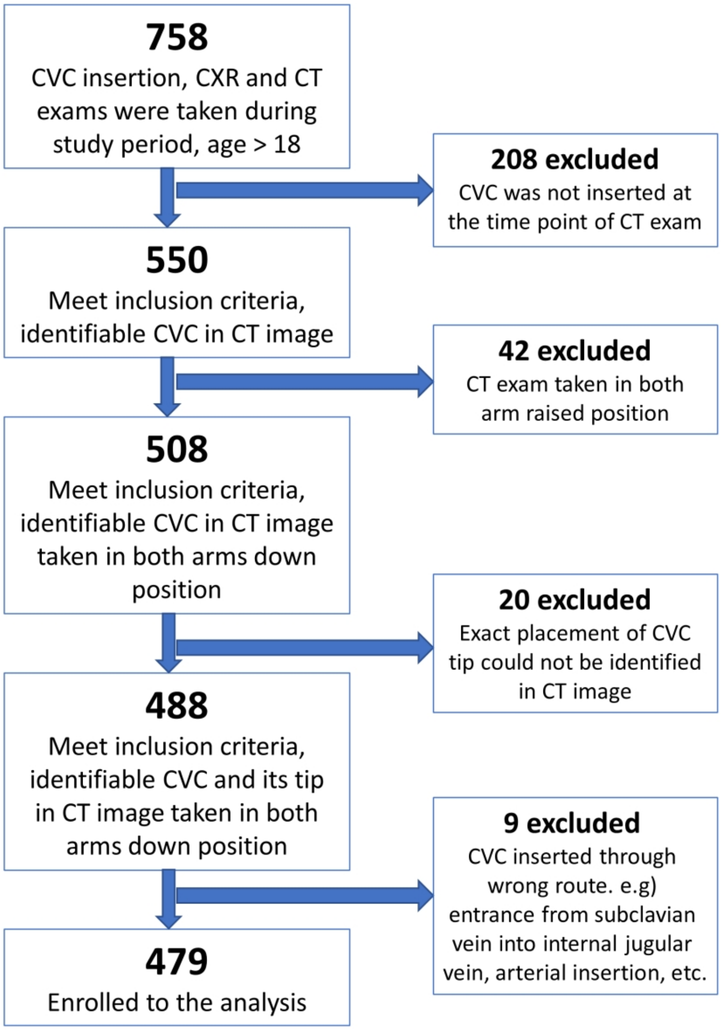

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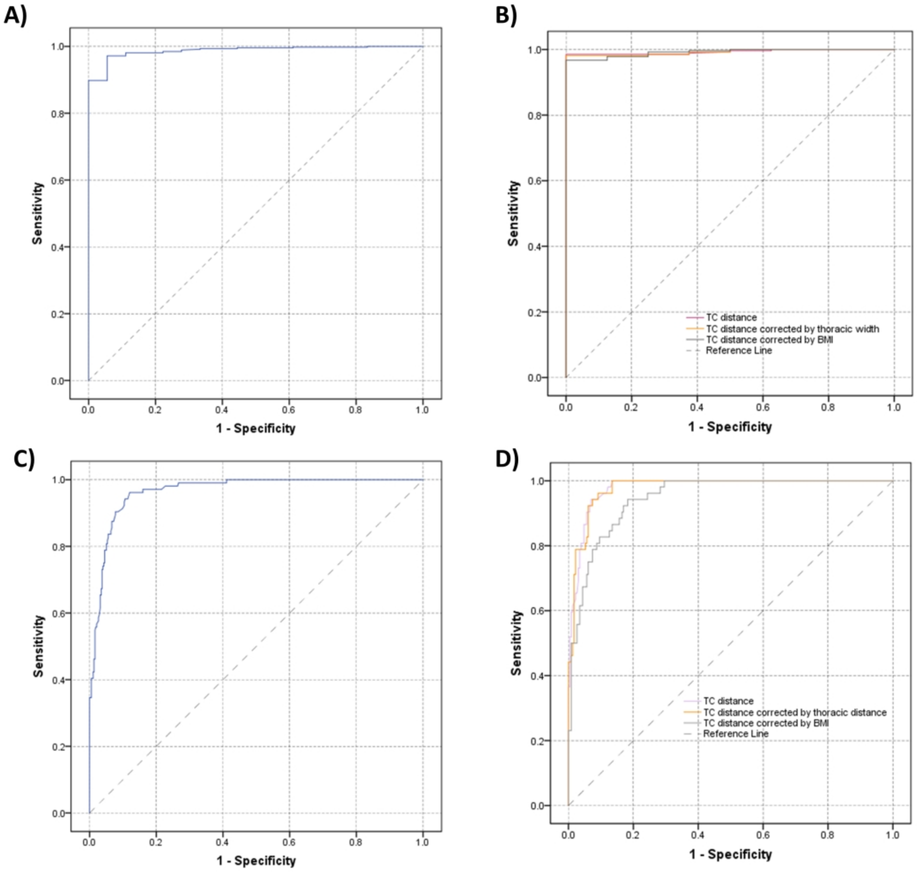
187x245mm (300 x 300 DPI)



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240x219mm (300 x 300 DPI)

Section & Topic	No	Item	Reported on page #
TITLE OR ABSTRACT			
	1	Identification as a study of diagnostic accuracy using at least one measure of accuracy (such as sensitivity, specificity, predictive values, or AUC)	2
ABSTRACT			
	2	Structured summary of study design, methods, results, and conclusions (for specific guidance, see STARD for Abstracts)	2
INTRODUCTION			
	3	Scientific and clinical background, including the intended use and clinical role of the index test	4
	4	Study objectives and hypotheses	4
METHODS			
Study design	**5**	Whether data collection was planned before the index test and reference standard were performed (prospective study) or after (retrospective study)	5
Participants	**6**	Eligibility criteria	5
	7	On what basis potentially eligible participants were identified (such as symptoms, results from previous tests, inclusion in registry)	5
	8	Where and when potentially eligible participants were identified (setting, location and dates)	5
	9	Whether participants formed a consecutive, random or convenience series	5
Test methods	**10a**	Index test, in sufficient detail to allow replication	5, 6
	10b	Reference standard, in sufficient detail to allow replication	
	11	Rationale for choosing the reference standard (if alternatives exist)	4
	12a	Definition of and rationale for test positivity cut-offs or result categories of the index test, distinguishing pre-specified from exploratory	9
	12b	Definition of and rationale for test positivity cut-offs or result categories of the reference standard, distinguishing pre-specified from exploratory	
	13a	Whether clinical information and reference standard results were available to the performers/readers of the index test	7
	13b	Whether clinical information and index test results were available to the assessors of the reference standard	
Analysis	**14**	Methods for estimating or comparing measures of diagnostic accuracy	6
	15	How indeterminate index test or reference standard results were handled	6
	16	How missing data on the index test and reference standard were handled	
	17	Any analyses of variability in diagnostic accuracy, distinguishing pre-specified from exploratory	6
	18	Intended sample size and how it was determined	
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Participants	**19**	Flow of participants, using a diagram	7
	20	Baseline demographic and clinical characteristics of participants	7
	21a	Distribution of severity of disease in those with the target condition	7
	21b	Distribution of alternative diagnoses in those without the target condition	
	22	Time interval and any clinical interventions between index test and reference standard	5
Test results	**23**	Cross tabulation of the index test results (or their distribution) by the results of the reference standard	7
	24	Estimates of diagnostic accuracy and their precision (such as 95% confidence intervals)	8
	25	Any adverse events from performing the index test or the reference standard	
DISCUSSION			
	26	Study limitations, including sources of potential bias, statistical uncertainty, and generalisability	10
	27	Implications for practice, including the intended use and clinical role of the index test	9
OTHER INFORMATION			
	28	Registration number and name of registry	
	29	Where the full study protocol can be accessed	
	30	Sources of funding and other support; role of funders	11

STARD 2015

AIM

STARD stands for “Standards for Reporting Diagnostic accuracy studies”. This list of items was developed to contribute to the completeness and transparency of reporting of diagnostic accuracy studies. Authors can use the list to write informative study reports. Editors and peer-reviewers can use it to evaluate whether the information has been included in manuscripts submitted for publication.

EXPLANATION

A **diagnostic accuracy study** evaluates the ability of one or more medical tests to correctly classify study participants as having a **target condition.** This can be a disease, a disease stage, response or benefit from therapy, or an event or condition in the future. A medical test can be an imaging procedure, a laboratory test, elements from history and physical examination, a combination of these, or any other method for collecting information about the current health status of a patient.

The test whose accuracy is evaluated is called **index test.** A study can evaluate the accuracy of one or more index tests. Evaluating the ability of a medical test to correctly classify patients is typically done by comparing the distribution of the index test results with those of the **reference standard**. The reference standard is the best available method for establishing the presence or absence of the target condition. An accuracy study can rely on one or more reference standards.

If test results are categorized as either positive or negative, the cross tabulation of the index test results against those of the reference standard can be used to estimate the **sensitivity** of the index test (the proportion of participants *with* the target condition who have a positive index test), and its **specificity** (the proportion *without* the target condition who have a negative index test). From this cross tabulation (sometimes referred to as the contingency or “2x2” table), several other accuracy statistics can be estimated, such as the positive and negative **predictive values** of the test. Confidence intervals around estimates of accuracy can then be calculated to quantify the statistical **precision** of the measurements.

If the index test results can take more than two values, categorization of test results as positive or negative requires a **test positivity cut-off**. When multiple such cut-offs can be defined, authors can report a receiver operating characteristic (ROC) curve which graphically represents the combination of sensitivity and specificity for each possible test positivity cut-off. The **area under the ROC curve** informs in a single numerical value about the overall diagnostic accuracy of the index test.

The **intended use** of a medical test can be diagnosis, screening, staging, monitoring, surveillance, prediction or prognosis. The **clinical role** of a test explains its position relative to existing tests in the clinical pathway. A replacement test, for example, replaces an existing test. A triage test is used before an existing test; an add-on test is used after an existing test.

Besides diagnostic accuracy, several other outcomes and statistics may be relevant in the evaluation of medical tests. Medical tests can also be used to classify patients for purposes other than diagnosis, such as staging or prognosis. The STARD list was not explicitly developed for these other outcomes, statistics, and study types, although most STARD items would still apply.

DEVELOPMENT

This STARD list was released in 2015. The 30 items were identified by an international expert group of methodologists, researchers, and editors. The guiding principle in the development of STARD was to select items that, when reported, would help readers to judge the potential for bias in the study, to appraise the applicability of the study findings and the validity of conclusions and recommendations. The list represents an update of the first version, which was published in 2003.

More information can be found on http://www.equator-network.org/reporting-guidelines/stard.

BMJ Open

Chest radiography for simplified evaluation of central venous catheter tip positioning for safe and accurate hemodynamic monitoring – a retrospective observational study

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Chest radiography for simplified evaluation of central venous catheter tip positioning for safe and accurate hemodynamic monitoring – a retrospective observational study

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Abstract

Objectives: The tip-to-carina (TC) distance on simple chest X-ray (CXR) has proven value in the determination of correct central venous catheter (CVC) positioning. However, previous studies have mostly focused on preventing the atrial insertion of the CVC tip, and not on appropriate positioning for accurate hemodynamic monitoring. We aimed to assess whether the TC distance could detect the passage of the CVC tip into the superior vena cava (SVC) and the right atrium (RA), and to accordingly suggest cutoff reference values for these two aspects.

Design: Retrospective observational cohort study.

Setting: Single urban tertiary level academic hospital.

Participants: 479 patients who underwent CXR and chest computed tomography (CT) after the insertion of a CVC with a 24-hour interval during the study period.

Intervention: The TC distance was measured on CXR, and the position of the CVC tip was assessed on the chest CT images. The TC distance was described as a negative or positive number if the CVC tip was above or below the carina, respectively. Receiver-operating characteristics curve (ROC) analyses were conducted to ascertain the TC distance to detect SVC entrance and RA insertion of CVC tip.

Results: The TC distance could significantly detect both SVC entrance and RA insertion ($P<0.001$ for both; area under curve 0.987 and 0.965, respectively), with a reference range of −6.69 to 15.61 mm.

Conclusion: The TC distance in CXR is a simple and precise method to confirm not only the safe placement of the CVC tip but also its optimal positioning for accurate hemodynamic monitoring.

Keywords

Catheterization, Central Venous; Hemodynamic Monitoring; Vena Cava, Superior; Heart Injuries

Article summary

Strengths and limitations of this study

- This is the first study that suggested specific range of the tip-to-carina distance on simple chest X-ray to ascertain correct positioning of central venous catheter tip in extracardiac superior vena cava.
- Our study only used the data whose chest X-ray and computed tomography were taken with same posture (both arms down), which could minimize possible errors caused by migration of central venous catheter tip.
- Our results were derived from a retrospective analysis of the dataset from single center, so the generalization of the results needs to be cautiously undertaken.

Introduction

Central venous catheter (CVC) insertion is a widely performed procedure that plays an important role in the care of critically ill patients, as well as patients who require parenteral nutrition, antibiotic therapy, chemotherapy, hemodialysis and patients with difficult peripheral venous access.[1] Central venous pressure (CVP), which is measured by CVC, is also the most frequently used hemodynamic parameter for fluid therapy of critically ill patients.[2]

The superior vena cava (SVC) is the largest central vein, and the CVP can be constantly measured regardless of whether the CVC tip is within the SVC or the right atrium (RA).[3] The SVC is the most suitable location to obtain CVP measurements due to the high blood flow velocity. However, if the CVC tip is inserted into RA, it may cause potentially fatal complications such as perforation, hemopericardium, and cardiac tamponade.[4-7] Therefore, the positioning of the CVC tip in the SVC such that RA insertion is prevented may be necessary for the prevention of possible fatal complications while retaining the capacity for precise CVP measurements. The lower one-third of the SVC, close to the junction of SVC and RA, is recommended as an appropriate catheter tip location.[8]

Various methods can be used to confirm the position of the CVC tip, and the gold standard is transesophageal echocardiography (TEE). However, the TEE is rarely available in clinical practice settings, except in specialist facilities that include a cardiac procedure room.[9-12] Chest X-ray (CXR) is the commonest tool to confirm the position of CVC tip because of its wide availability and relative low cost. Recently, point-of-care ultrasound has shown its value in the confirmation of CVC tip placement, and even showed superiority in many aspects compared with CXR.[13-15] However, sole use of ultrasound in real practice is restricted by various factors, and CXR is still used in almost every case of CVC tip placement.[16] With a CXR, the position of the CVC tip can be confirmed relative to various anatomical landmarks in the chest.[17-23] Among these, the tip-to-carina (TC) distance has been previously shown to be a reliable indicator in several studies.[19 22-24] However, the studies mostly focused on the prevention of intracardiac placement of the CVC tip, but not on the confirmation of appropriate positioning of the CVC tip in the SVC, which is essential for accurate hemodynamic monitoring.

We hypothesized that the TC distance that is measured on simple CXR is appropriate for confirming the proper placement of the CVC tip, and can prevent intracardiac placement of the CVC while retaining the ability to accurately measure the hemodynamic status. We aimed to evaluate this hypothesis, and to ascertain reference

values of the TC distance to facilitate the confirmation of appropriate placement of the CVC tip.

Material and Methods

Patient and Public Involvement

No patient involved.

Type of Study

The protocol for this retrospective observational study was reviewed and approved by the institutional ethics committee (Ethical Committee of CHA University, CHA Bundang Medical Center, approval no. 2019-11-068). The ethical body waived the need for written informed consent, and approved anonymized data collection through chart reviews in the electronic medical record (EMR) system.

Study Population and Eligibility

This study included adult patients (age ≥18 years) who visited the ED of CHA Bundang Medical Center, a tertiary-level teaching hospital with more than 85,000 yearly emergency department (ED) visits, between January 2, 2016 and July 2, 2018 and underwent CXR and chest computed tomography (CT) within 24 hours of CVC insertion. The exclusion criteria were: 1) age less than 18 years, 2) abnormal chest anatomy (e.g., lung cancer),[25] 3) difficultly in ascertaining the position of the CVC tip on a chest CT or CXR image, and 4) the chest CT is performed with both arms raised.[26]

Data Collection

Data on patient demographics and characteristics, including the height and the weight, were obtained through a review of the EMRs. Chest CT were conducted on a 64-slice multidetector-row CT (Light-speed VCT, GE HealthCare, Milwaukee, WI, USA) with the following scanning parameters: 120 kV, 200 mA, 0.625 mm collimation, 1.5 mm increment, 3 mm reconstruction. In addition, 60 to 120 mL ioversol (Optiray 320 mg/ml, Tyco Healthcare, Montreal, Canada) was intravenously injected, based on the patient's body mass index (BMI) (3 mL per BMI, 20 mL if BMI<20, and 120 mL if BMI>40). The scan range for the chest CT extended from the lower half of the neck to the adrenal glands, and both chest CT and CXR were conducted with the patient in the supine position with both arms down.

The presence of CVC, SVC entrance, and RA insertion of the CVC tip were verified in the chest CT and CXR images by using Picture Archiving and Communications System (PACS; Marosis, Seoul, Korea). The decision was made based on the agreement of two separate researchers. On CT imaging, the identification of the CVC tip below the crista terminalis confirmed RA insertion, whereas tip location below the level of where both the brachiocephalic veins merge to form the SVC was defined as an entrance into the SVC.

A horizontal line perpendicular to the carina and CVC tip was drawn in the CXR image and on the CT scout image. Using the distance measurement function of PACS, the vertical distance of the two horizontal lines was measured and recorded as the TC distance. All TC distance measurements were undertaken by the same author. The carina level was defined as zero; the TC distance was described as a negative or positive number if the CVC tip was above or below the carina, respectively. The thoracic width was measured as the distance between the two points where the line perpendicular to the body axis at the level of the ceiling of the right diaphragm met the internal surface of the ribs (Figure 1). The TC distance was measured both from CXR and the scout film of the chest CT, and the distances were compared to confirm the reliability of the CXR measurement. The TC distance was divided by the BMI (body weight [kg]/height^2 [m]) and by the thoracic width to obtain body size-adjusted values.

Outcomes

The primary outcome was the detection of SVC entrance and RA insertion of the CVC tip, and secondary outcomes were the reference TC distance range indicating the SVC entrance and extracardiac placement of the CVC tip, and the relative predictive ability of body size-adjusted TC distance values.

Statistical Analysis

Data with normal distribution are presented as mean ± standard deviation (SD), and nonparametric data are presented as the median (interquartile range [IQR]). The comparison of continuous variables was undertaken with the independent t-test or the Mann–Whitney U test for data with normal or non-normal distribution respectively. The matched-pair analysis of TC distances measured from the CXR and chest CT images were undertaken with the Wilcoxon signed ranks test. We conducted receiver-operating characteristics (ROC) analysis to assess the predictive ability of the TC distance in the CXR images to ascertain the SVC entrance or RA insertion of the CVC tip, and the AUC was calculated to quantify the predictive ability. The ROC analyses were repeated with the body size-adjusted TC distance values, and their AUCs were compared with those of the TC distance values by using the DeLong test.[27] The cutoff point of the TC distance to detect SVC passage of the CVC tip was defined as a value that could maximize sensitivity while maintaining 100% specificity. Similarly, the cutoff point to detect RA insertion was defined as a value that maximized specificity while maintaining 100% sensitivity. All statistical analyses were conducted in IBM SPSS Statistics 26.0 (IBM Corp., Armonk, New York, USA), except for the comparison of ROC curves for which we used R v 4.0.0 (The R Foundation for Statistical Computing, https://www.r-project.org/foundation/). Statistical significance was set to a P-value <0.05.

Results

Participant Characteristics

During the study period, a total of 758 patients met the inclusion criteria, and 479 of them were included in the final analysis dataset after the exclusion of 279 patients (Figure 2). The baseline data of the study participants are described in Table 1. There was no significant difference between the TC distance measured on CXR and on the scout film of the chest CT (P=0.638).

Table 1. Baseline characteristics of the study participants

		Total	SVC entrance		RA insertion	
			No (n=18)	Yes (n=461)	No (n=375)	Yes (n=104)
Male sex		254	11, 4.3%	243, 95.7%	221, 87.0%	33, 13.0%
Age		73 (58–80)	74.5 (55–78)	73 (58–80)	74 (61–81)	69 (52–77.5)
Height		161 (155–168)	157 (151–159)	162 (155–168)	162 (155–170)	159.5 (155–165.8)
Weight		56.0 (48.7–67.5)	58.5 (47.6–66.8)	56.0 (48.7–68.0)	55.7 (48.0–66.4)	57.1 (50.9–70.4)
BMI		21.4 (18.8–25.2)	24.6 (19.0–28.4)	21.3 (18.8–25.0)	21.1 (18.5–24.9)	22.9 (19.6–26.8)
Access	IJV	101	10, 9.9%	91, 90.1%	93, 92.1%	8, 7.9%
	SCV	378	8, 2.1%	370, 97.9%	282, 74.6%	96, 25.4%
Thoracic width		288.7 ± 22.4	289.6 ± 21.9	288.6 ± 22.4	290.3 ± 22.3	282.8 ± 21.6
TC distance, CXR[a]		18.6 (4.2–32.6)	−49.9 (−53.3 to −28.7)	20.0 (6.4–34.8)	11.6 (−0.7 to 23.9)	47.0 (38.4–60.8)
TC distance, scout[b]		18.6 (4.6–33.5)	−39.9 (−56.3 to −29.7)	20.0 (6.6–34.6)	11.5 (0.3–23.9)	47.5 (38.7–60.3)

Unit of the measurements: male sex (n, %), age (year), height (cm), weight (kg), access (n, %), thoracic width (mm), and TC distance (mm). Numerical values are described as median (interquartile range), except for male sex (n, %), access (n, %), and thoracic width (mean ± SD). CXR: chest X-ray; SVC: superior vena cava, RA: right atrium, IJV: internal jugular vein, SCV: subclavian vein, TC: tip-to-carina. [a]TC distance measured on the simple chest X-ray, [b]TC distance measured on the scout film of the chest CT.

Ability of TC distance and Body size-adjusted TC Distance for Detecting SVC Entrance and RA Insertion

The TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI could all significantly detect the SVC entrance of the CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by thoracic width, and the TC distance corrected by the BMI were 0.987, 0.989, and 0.992, respectively. (Figure 3A and 3B). There was no statistically significant difference in the comparisons of ROC curves of the TC distance with those of the TC distance corrected by the thoracic width as well as those of the TC distance corrected by the BMI (P=0.189 and 0.8258, respectively). The cutoff value of the TC distance to detect the SVC entrance of the CVC tip was −6.70mm (sensitivity 89.8% and specificity 100%).

The TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by the BMI could all significantly detect RA insertion of the CVC tip (P<0.001 for all). The AUCs of the TC distance, the TC distance corrected by the thoracic width, and the TC distance corrected by BMI were 0.966, 0.966, and 0.947, respectively (Figure 3C and 3D). There was a statistically significant difference between ROC curves of the TC distance and the TC distance corrected by the BMI. However, there was no significant difference between the ROC curves of the TC distance and the TC distance corrected by the thoracic width (P=0.995 and 0.001, respectively). The cutoff value of the TC distance to detect the RA insertion of the CVC tip was 15.62 mm (sensitivity 100% and specificity 58.93%).

Discussion

The results of the present study showed that the TC distance on the CXR is a useful parameter to confirm the appropriate positioning of the CVC tip, not only to prevent intracardiac placement that can cause serious complications, but also to ensure SVC placement for accurate CVP monitoring. Furthermore, we ascertained the optimal reference range of the TC distance based on the results.

Previous studies of methods to confirm the location of CVC tip, including those that evaluated the TC distance on simple CXR, were undertaken to only assess the ability of imaging to avoid intracardiac placement of the CVC tip.[9-12 17-24 28-31] The results of this study confirmed that the TC distance in the CXR could confirm not only extracardiac placement but also the SVC entrance of the CVC tip. The confirmation of intra-SVC placement of CVC tip is a prerequisite for accurate CVP monitoring, which is a crucial factor when considering the purpose of such an invasive procedure.

The results of recent clinical trials suggest that CVP may not be a reliable index for assessing fluid responsiveness, and the use of CVP for such a purpose is not recommended in the most of clinical guidelines any more, despite its widespread utilization.[32 33] Moreover, intracardiac placement of CVC is not that dangerous as was before, owing to the development of the material.[34] These facts may devalue the precise confirmation of CVC tip placement. However, CVP measurement still has some valuable aspects, and, most of all, it is still the most frequently used hemodynamic variable for deciding when to start fluid administration during critical care.[35] Furthermore, it may be unethical to take an unnecessary risk even if it is minimal. Hence, the positioning of CVC tip in an appropriate place is still important as long as CVP insertion is performed.

The body size-adjusted TC distance showed similar or even a significantly inferior ability to detect the SVC entrance and RA insertion of the CVC tip than the unadjusted TC distance in the present dataset. This result indicates that the body size-adjustment of the TC distance to confirm appropriate positioning of the CVC tip is not necessary.

We specified cutoff values to confirm the SVC insertion of the CVC tip as the value with maximal sensitivity and a specificity of 100%. Similarly, we specified the cutoff value for intracardiac insertion of the CVC tip as a

value with maximal specificity and a sensitivity of 100%. These cutoffs were defined on the premise that it was more important to prevent false-positive than false-negative results for the determination of SVC entrance. Otherwise, the prevention of false-negative is more important than that of false-positive in the determination of intracardiac placement, with due consideration of their purposes. Thus, we obtained a range of TC distance (−6.69 to 15.61 mm) that could assure both SVC insertion and extracardiac placement of CVC tip. One may think that the cutoff value to detect intracardiac insertion can cause critical error in practice, because significantly high false-positive rate is expected. However, what we have to do in the case that TC distance exceed the cutoff value indicating intracardiac insertion is just a simple moving backward of CVC tip within the suggested range of TC distance. Hence, the proper positioning of CVC tip can be easily maintained even in the case of false detection of intracardiac insertion. This range also confirms the results of previous studies that suggested the carina as an anatomical landmark for the determination of CVC tip positioning based on anatomical analyses of cadavers or chest magnetic resonance imaging (MRI)/CT, given that the carina is definitely included in the cutoff range.[17 22] The carina in the CXR can be considered to be a simpler landmark, based on the results of both, the present and the previous studies, and we can ascertain safe and precise positioning of the CVC tip if the tip is located within the range of the TC distance between −6.69 and 15.61 mm.

A recent study by Dulce et al.[30] that analyzed the topographic relationships of the extrapericardial SVC by using CXR and CT imaging suggested that a location 9 mm above the carina (TC distance −9 mm) was the appropriate position for CVC tip placement, which is quite different from that of our results. We excluded the data on individuals whose chest CT images were obtained with both arms raised. However, the study of Dulce et al. mostly used the data of participants whose CT images were obtained with both arms raised. This prominent discordance may be attributable to the differences in arm position during the chest CT examination, considering that the position of the CVC tip can change when both the arms are raised.[26] The range of the TC distance determined from the present analysis could be more reliable as a reference range for the TC distance on CXR images, because the CXR is obtained with both arms downward in almost every condition.

The present study has some limitations. First, our study was a retrospective analysis of the dataset from single center, and there may be a potential bias in our results due to the incompleteness of our dataset (especially with regard to the body-size parameters) or a possible bias in the characteristics of the study participants. Therefore, the generalization of the results of this study needs to be cautiously undertaken. Second, the actual CVC tip

position could be different at the time point of CXR and chest CT imaging, because of the maximum 24-hour interval between the CXR and chest CT examinations. However, the result of paired comparison of CT distances measured from both CXR and chest CT imaging in the present dataset revealed that the influence of this factor was minimal. Nevertheless, there could still be a chance of significant CVC tip migration, considering that even the respiratory phases could affect CVC tip position.[36] Third, we excluded some cases during data collection because of the difficultly in ascertaining the position of the CVC tip on a chest CT image, and this could cause a selection bias although we made every effort not to exclude a case intentionally. The exclusion was carefully decided only when two independent researchers agreed that CVC tip was unidentifiable due to poor image quality or being obscured by contrast media.

Conclusions

The TC distance in CXR is a simple and precise method to confirm not only the safe placement of the CVC tip but also its optimal positioning for accurate hemodynamic monitoring. The TC distances in the range of −6.69 to 15.61 mm can be used as a reference range to define cutoffs for the optimal positioning of the CVC tip.

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Competing interests statement

: The authors declare no conflict of interest.

Author contributions

: Conceptualization, Tae Nyoung Chung; Data curation, Sujin Moon; Formal analysis, Tae Nyoung Chung; Funding acquisition, Jinkun Bae; Investigation, Minwoo Kang, Jinkun Bae and Sujin Moon; Methodology, Tae Nyoung Chung; Visualization, Minwoo Kang; Writing – original draft, Minwoo Kang and Jinkun Bae; Writing – review & editing, Tae Nyoung Chung.

Data statement

: Data are available in a public, open access repository. 10.6084/m9.figshare.12403445

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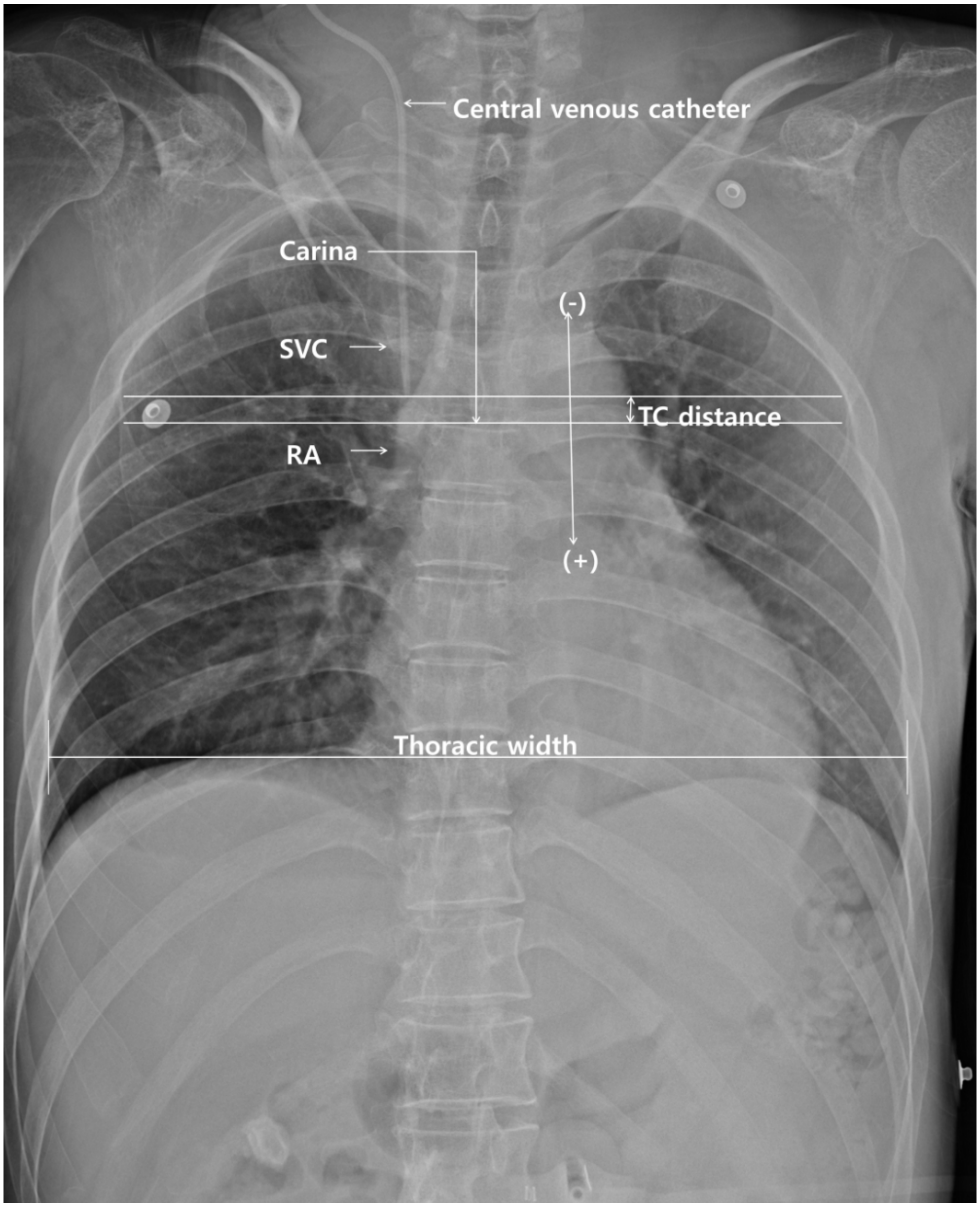
Figure legends

Figure 1. Definition of the tip-to-carina (TC) distance: Each horizontal line perpendicular to the carina and central venous catheter (CVC) tip was drawn on the simple chest X-ray image. The vertical distance of the two horizontal lines was measured and defined as the TC distance. The position in the carina is defined as zero, and positioning of the CVC tip above (-) or below (+) the carina is recorded. SVC: superior vena cava; RA: right atrium

Figure 2. Flow diagram of the patient disposition in the study. CVC: central venous catheter; CXR: simple chest X-ray; CT: computed tomography.

Figure 3. Receiver operating characteristics (ROC) curves of the tip-to-carina (TC) distance and the body size-adjusted TC distance. A) ROC curve of the TC distance to detect the passage of the central venous catheter (CVC) tip into the superior vena cava (SVC); B) comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the SVC passage of the CVC tip; C) ROC curve of the TC distance to detect the entrance of the CVC tip into the right atrium (RA); and D) the comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the RA entrance of the CVC tip.



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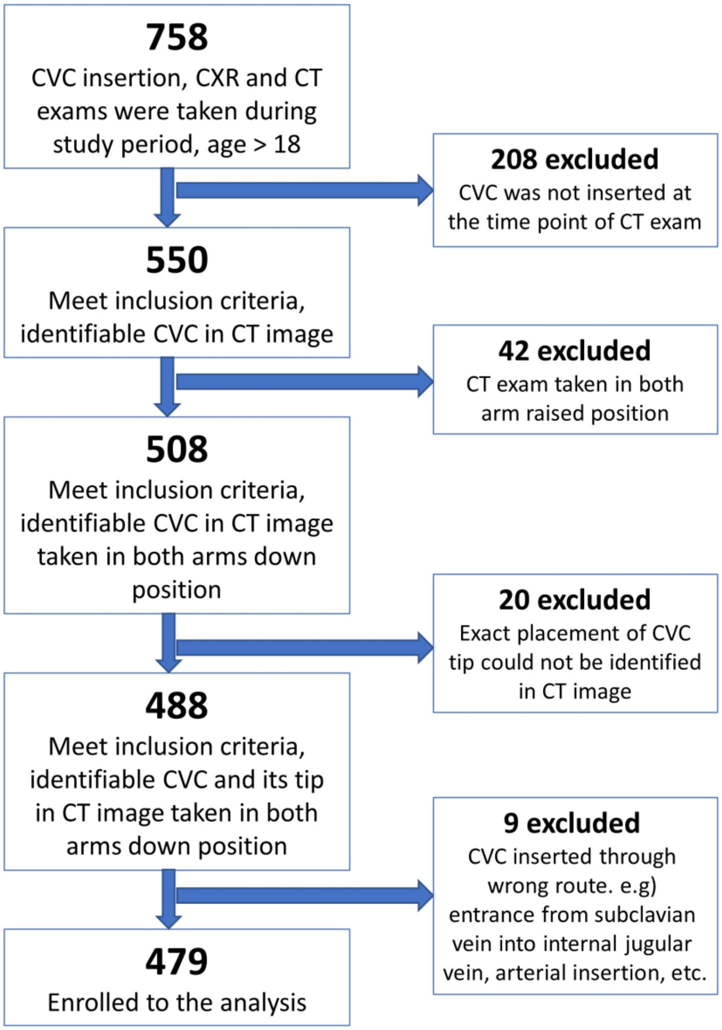

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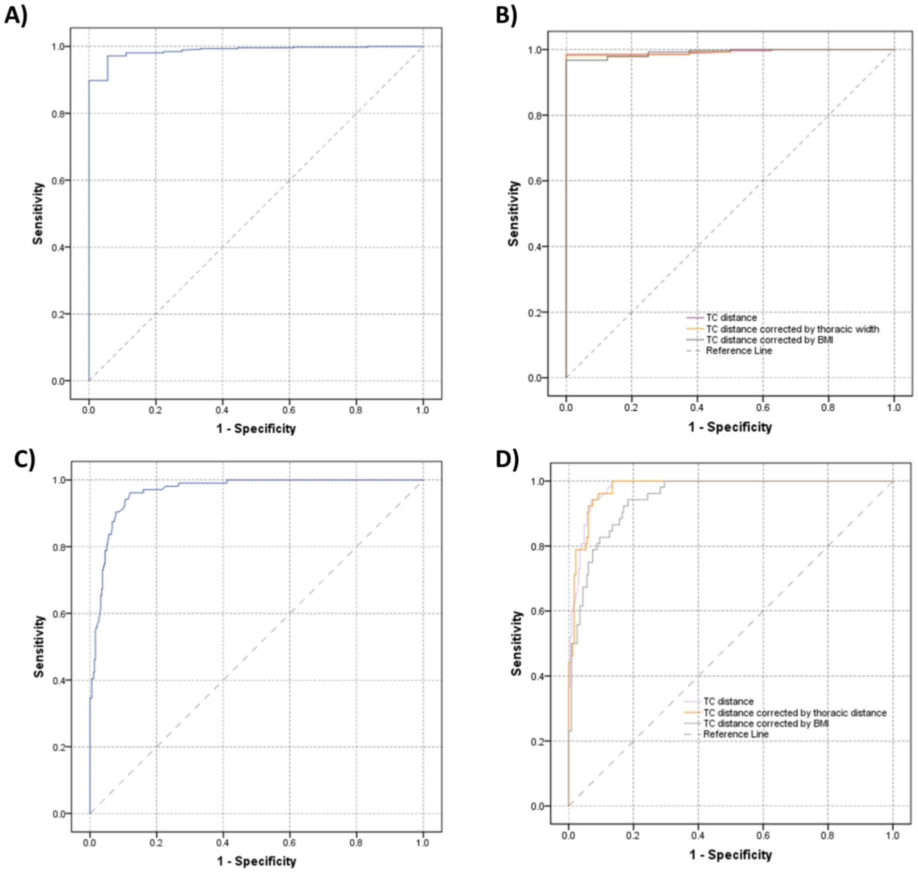

Figure 3. Receiver operating characteristics (ROC) curves of the tip-to-carina (TC) distance and the body size-adjusted TC distance. A) ROC curve of the TC distance to detect the passage of the central venous catheter (CVC) tip into the superior vena cava (SVC); B) comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the SVC passage of the CVC tip; C) ROC curve of the TC distance to detect the entrance of the CVC tip into the right atrium (RA); and D) the comparison of the ROC curves of the TC distance and the body size-adjusted TC distance to detect the RA entrance of the CVC tip.

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Section & Topic	No	Item	Reported on page #
TITLE OR ABSTRACT			
	1	Identification as a study of diagnostic accuracy using at least one measure of accuracy (such as sensitivity, specificity, predictive values, or AUC)	2
ABSTRACT			
	2	Structured summary of study design, methods, results, and conclusions (for specific guidance, see STARD for Abstracts)	2
INTRODUCTION			
	3	Scientific and clinical background, including the intended use and clinical role of the index test	4
	4	Study objectives and hypotheses	4
METHODS			
Study design	**5**	Whether data collection was planned before the index test and reference standard were performed (prospective study) or after (retrospective study)	5
Participants	**6**	Eligibility criteria	5
	7	On what basis potentially eligible participants were identified (such as symptoms, results from previous tests, inclusion in registry)	5
	8	Where and when potentially eligible participants were identified (setting, location and dates)	5
	9	Whether participants formed a consecutive, random or convenience series	5
Test methods	**10a**	Index test, in sufficient detail to allow replication	5, 6
	10b	Reference standard, in sufficient detail to allow replication	
	11	Rationale for choosing the reference standard (if alternatives exist)	4
	12a	Definition of and rationale for test positivity cut-offs or result categories of the index test, distinguishing pre-specified from exploratory	9
	12b	Definition of and rationale for test positivity cut-offs or result categories of the reference standard, distinguishing pre-specified from exploratory	
	13a	Whether clinical information and reference standard results were available to the performers/readers of the index test	7
	13b	Whether clinical information and index test results were available to the assessors of the reference standard	
Analysis	**14**	Methods for estimating or comparing measures of diagnostic accuracy	6
	15	How indeterminate index test or reference standard results were handled	6
	16	How missing data on the index test and reference standard were handled	
	17	Any analyses of variability in diagnostic accuracy, distinguishing pre-specified from exploratory	6
	18	Intended sample size and how it was determined	
RESULTS			
Participants	**19**	Flow of participants, using a diagram	7
	20	Baseline demographic and clinical characteristics of participants	7
	21a	Distribution of severity of disease in those with the target condition	7
	21b	Distribution of alternative diagnoses in those without the target condition	
	22	Time interval and any clinical interventions between index test and reference standard	5
Test results	**23**	Cross tabulation of the index test results (or their distribution) by the results of the reference standard	7
	24	Estimates of diagnostic accuracy and their precision (such as 95% confidence intervals)	8
	25	Any adverse events from performing the index test or the reference standard	
DISCUSSION			
	26	Study limitations, including sources of potential bias, statistical uncertainty, and generalisability	10
	27	Implications for practice, including the intended use and clinical role of the index test	9
OTHER INFORMATION			
	28	Registration number and name of registry	
	29	Where the full study protocol can be accessed	
	30	Sources of funding and other support; role of funders	11

STARD 2015

AIM

STARD stands for “Standards for Reporting Diagnostic accuracy studies”. This list of items was developed to contribute to the completeness and transparency of reporting of diagnostic accuracy studies. Authors can use the list to write informative study reports. Editors and peer-reviewers can use it to evaluate whether the information has been included in manuscripts submitted for publication.

EXPLANATION

A **diagnostic accuracy study** evaluates the ability of one or more medical tests to correctly classify study participants as having a **target condition.** This can be a disease, a disease stage, response or benefit from therapy, or an event or condition in the future. A medical test can be an imaging procedure, a laboratory test, elements from history and physical examination, a combination of these, or any other method for collecting information about the current health status of a patient.

The test whose accuracy is evaluated is called **index test.** A study can evaluate the accuracy of one or more index tests. Evaluating the ability of a medical test to correctly classify patients is typically done by comparing the distribution of the index test results with those of the **reference standard**. The reference standard is the best available method for establishing the presence or absence of the target condition. An accuracy study can rely on one or more reference standards.

If test results are categorized as either positive or negative, the cross tabulation of the index test results against those of the reference standard can be used to estimate the **sensitivity** of the index test (the proportion of participants *with* the target condition who have a positive index test), and its **specificity** (the proportion *without* the target condition who have a negative index test). From this cross tabulation (sometimes referred to as the contingency or “2x2” table), several other accuracy statistics can be estimated, such as the positive and negative **predictive values** of the test. Confidence intervals around estimates of accuracy can then be calculated to quantify the statistical **precision** of the measurements.

If the index test results can take more than two values, categorization of test results as positive or negative requires a **test positivity cut-off**. When multiple such cut-offs can be defined, authors can report a receiver operating characteristic (ROC) curve which graphically represents the combination of sensitivity and specificity for each possible test positivity cut-off. The **area under the ROC curve** informs in a single numerical value about the overall diagnostic accuracy of the index test.

The **intended use** of a medical test can be diagnosis, screening, staging, monitoring, surveillance, prediction or prognosis. The **clinical role** of a test explains its position relative to existing tests in the clinical pathway. A replacement test, for example, replaces an existing test. A triage test is used before an existing test; an add-on test is used after an existing test.

Besides diagnostic accuracy, several other outcomes and statistics may be relevant in the evaluation of medical tests. Medical tests can also be used to classify patients for purposes other than diagnosis, such as staging or prognosis. The STARD list was not explicitly developed for these other outcomes, statistics, and study types, although most STARD items would still apply.

DEVELOPMENT

This STARD list was released in 2015. The 30 items were identified by an international expert group of methodologists, researchers, and editors. The guiding principle in the development of STARD was to select items that, when reported, would help readers to judge the potential for bias in the study, to appraise the applicability of the study findings and the validity of conclusions and recommendations. The list represents an update of the first version, which was published in 2003.

More information can be found on http://www.equator-network.org/reporting-guidelines/stard.