General Anesthesia

Transesophageal echocardiographic evaluation of ECG-guided central venous catheter placement

[Évaluation échocardiographique transœsophagienne de la mise en place d'un cathéter veineux central guidée par ECG]

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Purpose: To facilitate electrocardiography (ECG)-guided central venous catheter placement by observing the shape and size of the P wave at specific locations of a central venous catheter (CVC) tip.

Methods: We evaluated 54 patients for whom central venous catheterization was planned as part of routine care for their elective surgery. The junction of the superior vena cava (SVC) and the right atrium (RA) was defined as the superior border of the crista terminalis by transesophageal echocardiography. The RA ECGs were recorded while withdrawing the CVC into the SVC or advancing it into the RA at 1-cm intervals. Saline was used as an electrical conductor via the distal lumen of the CVC.

Results: The tallest peaked and biphasic P waves [median (interquartile range)] were observed when the CVC tip was located at positions 0.0 cm (-1.0 to 0.0) and -4.0 cm (-5.0 to -3.0) below the SVC/RA junction, respectively. The P wave returned to a normal shape and size at 4.0 cm (3.0 to 4.0) above the SVC/RA junction. Overshoot P waves were observed at -4.0 cm (-5.0 to -3.0) below the SVC/RA junction in 22 patients, when the CVC tip appeared to be contacting or in close proximity to the RA wall.

Conclusions: During ECG-guided central venous catheterization, the tallest peaked P wave may be used to place the CVC tip at the SVC/RA junction, the normally-shaped P wave identifies the mid to upper SVC, and biphasic P waves identify RA localization.

***Objectif** : Faciliter la pose d'un cathéter veineux central (CVC) guidée par électrocardiographie (ECG), observant la forme et la taille de l'onde P à des sites spécifiques de la pointe du cathéter.*

***Méthode** : Nous avons évalué 54 patients après insertion d'un cathéter veineux central, partie des soins courants de l'intervention chirurgicale réglée. La jonction de la veine cave supérieure (VCS) et de l'oreillette droite (OD), définie par échocardiographie transœsophagienne, correspondait au bord supérieur de la crête terminale. Les ECG de l'OD ont été enregistrées lors du retrait du CVC de la VCS ou quand il a été poussé dans l'OD à intervalles de 1 cm. Une solution salée a servi de conducteur électrique passant par la lumière distale du CVC.*

***Résultats** : Les ondes P maximales et biphasiques [médiane (écart interquartile)] ont été observées quand la pointe du CVC était respectivement à 0,0 cm (-1,0 à 0,0) et à -4,0 cm (-5,0 à -3,0) sous la jonction VCS/OD. L'onde P a repris une forme et une taille normales à 4,0 cm (3,0 à 4,0) au-dessus de la jonction SVC/OD. Le dépassement des ondes P a été observé à -4,0 cm (-5,0 à -3,0) sous la jonction VCS/OD chez 22 patients au moment où la pointe du CVC paraissait en contact avec la paroi de l'OD ou très près d'elle.*

***Conclusion** : Pendant le cathétérisme veineux central guidé par ECG, l'onde P maximale peut servir à placer la pointe d'un cathéter veineux central à la jonction VCS/OD, l'onde P de forme normale indique la VCS, de son milieu à sa partie supérieure, et l'onde P biphasique situe l'OD.*

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DEPENDING on the point of entry or indication for a central venous catheter (CVC), the optimal site for CVC tip placement varies.[1] The junction of the superior vena cava (SVC) with the right atrium (RA) may be the best position for the efficient aspiration of air when air embolism occurs.[2] The RA is recommended as the most appropriate position of a hemodialysis catheter tip to ensure optimal blood flow.[3,4] The upper SVC is suitable only for tips of CVCs placed via the right internal jugular vein, but risking thrombosis.[1] To prevent possible cardiac tamponade caused by CVC, it is suggested that the CVC should be located outside the pericardial reflection on the SVC, and not just outside the RA.

Unfortunately, clinicians have lacked reliable surface landmarks to position the CVC accurately without diagnostic testing. For anesthesiologists, routine use of fluoroscopy or post-procedure portable *x-rays* would lengthen operative time and increase costs. Additionally, such routine testing would expose operating room personnel and patients to extra irradiation. Using electrocardiography (ECG)-guided central venous catheterization, radiation hazards can be minimized and the costs of CVC placement can be reduced.[5]

Electrocardiography-guided central venous catheterization has been reported to be accurate and successful.[6–8] However, variations in the methodology exist, and the results evaluated radiologically appear to be inconsistent.[5,7–11] Chu *et al.*[12] have evaluated ECG-guided central venous catheterization using transesophageal echocardiography (TEE). However, this study was performed while analyzing only the tallest peaked P wave. There are no studies which describe the exact position of CVCs when the associated P wave displays are either biphasic or normal in shape. We therefore undertook a prospective descriptive clinical study using TEE guidance to establish the absolute locations and ranges of CVC tip positions when specific P wave patterns are displayed, and, thereby, to provide more accurate assessment of CVC localization during ECG-guided central venous catheterization.

Methods

After internal Review Board approval (Seoul National University Hospital, Seoul, Korea) and obtaining informed consent from each subject, we studied male and female adult patients for whom central venous catheterization was planned as part of their routine care for elective surgery. Any P wave abnormalities by pacemaker, dilated RA or arrhythmias such as atrial fibrillation on the preoperative ECG, or any contraindication to TEE resulted in exclusion.

In the operating room routine monitors were applied. Following induction of general anesthesia, the patient's trachea was intubated and the lungs were mechanically ventilated to maintain normocarbia. A multi-plane TEE probe (Sonos 5500 imaging system, Philips, Andover, MA, USA) was placed into the patient's esophagus and a bicaval view was obtained. All cannulations were performed by two anesthesiologists (Y.-S. Jeon and J.-H. Kim) with more than eight years' experience in landmark-guided internal jugular vein access. Because only the right-side internal jugular vein was cannulated, the patient was placed in Trendelenburg position with the head turned to the left and the neck extended. Using standard technique, the needle was directed toward the ipsilateral nipple. A 30-cm-long, double- or triple-lumen CVC (B Braun, Mesungen, Germany) was advanced using a sterile Seldinger technique. After cannulation, the patient was returned to a horizontal plane.

During ECG-guided central venous catheterization, normal saline in the distal lumen of the CVC was used as the intravascular electrode to conduct electrical signals from the heart. The leads were attached to a standard three-lead ECG system. Lead II was monitored with the right arm lead (the negative electrode), the left leg lead (the positive electrode) and the left arm lead (the ground). The right arm electrode in standard lead II configuration was attached to a hypodermic needle passed through the injection port of a male Luer-lock injection cap on the distal lumen of the CVC. The distal lumen of the CVC was carefully aspirated to remove any air bubbles and then flushed with sterile heparinized saline. The inserted hypodermic needle was connected to the right arm electrode of the ECG monitor using a pre-sterilized electric wire with alligator clamps at both ends, creating a catheter-to-left-leg lead. Real-time monitoring of the ECG tracing was conducted at the bedside with a portable 12-lead monitor terminal (MAC 5000; Marquette, Milwaukee, WI, USA).

Next, under TEE guidance on a bicaval view, the CVC was advanced until the tip of CVC reached the SVC/RA junction. Echocardiographically, this was defined as the base of the superior edge of the crista terminalis.[13] To localize the CVC tip at the junction accurately, the bicaval and short axis views, longitudinal and right-angled to the CVC axis, were alternated to observe the distal CVC tip on the TEE frame while moving the TEE probe backwards and forwards. Agitated saline was flushed through the distal end of the CVC to facilitate identification of the tip.

When the CVC tip was positioned at the SVC/RA junction, the ECG was recorded on a portable 12-lead

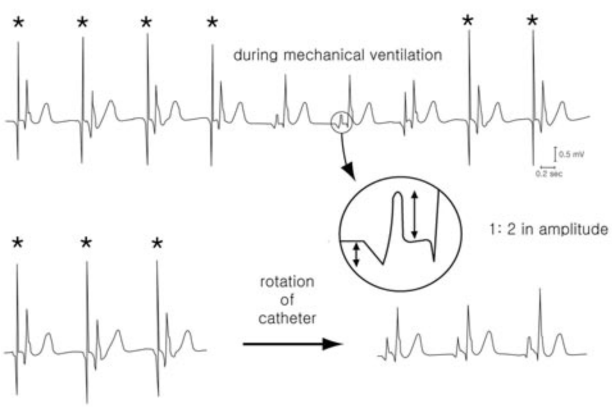

FIGURE 1 When the central venous catheter tip was located in the right atrium (RA) the overshoot P wave (marked with *) alternated with the characteristic biphasic P wave by minimal movement of the chest, which occurred during mechanical ventilation (upper part of panel). A biphasic P wave was defined as a wave where the amplitude of the negative deflection of the P wave approximated half the later positive deflection (inset). The overshoot P wave frequently disappeared, but returned to a characteristic pattern on rotating the central venous catheter (lower part of panel).

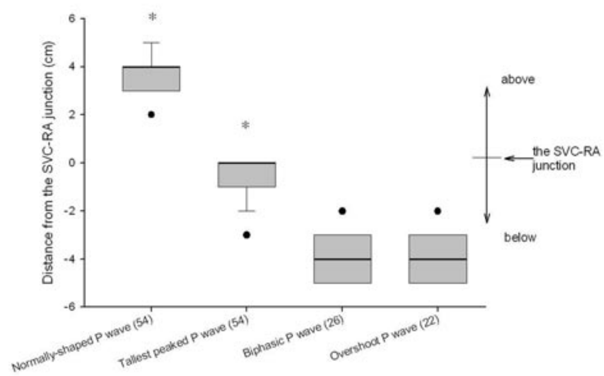

FIGURE 2 The distributions of central venous catheter tip locations when superior vena cava (SVC) or right atrial (RA) electrocardiography showed characteristic P waves. *$P < 0.05$ *vs* biphasic and overshoot P waves. The *normally-shaped P wave* ($n = 54$) was defined by consensus when the P wave appeared to have a normal size and shape compared with the P wave of conventional lead II. The *tallest peaked P wave* ($n = 54$) was defined at the peak amplitude of the P wave, and the (characteristic) *biphasic P wave* ($n = 26$) occurred when the amplitude of negative deflection of the P wave approximated half the later positive deflection. The *overshoot P wave* ($n = 22$) was defined as abrupt overshooting changes in the amplitude of P wave such as when CVC tips were making contact or in close proximity to the RA wall on transesophageal echocardiography. Zero position refers to localization at the SVC/RA junction. Positive values refer to proximal localization above the SVC/RA junction, and negative values to distal localization below the SVC/RA junction. Data are shown as box and whisker plots: the box boundaries show the 25th to 75th percentiles; a thick line within the box indicates the median; whiskers above and below the box indicate the 10th to 90th percentiles; and dots represent outliers.

monitor. The CVC was advanced at 1-cm intervals until it reached 5 cm below the SVC/RA junction. The CVC was then withdrawn to the SVC/RA junction and the P wave appearance was rechecked. Thereafter, the CVC was withdrawn at 1-cm intervals to 7 cm above the SVC/RA junction. Each ECG tracing (lead II) was recorded at 1-cm intervals from 5 cm below the SVC/RA junction to 7 cm above it.

The tallest peaked P wave was defined at the peak amplitude of the P wave. The P wave was considered biphasic whenever the amplitude of the negative deflection approximated half the amplitude of the later positive P wave deflection, and the negative deflection was more than 1 mm in width at a standard ECG sweep speed of 25 mm·sec^{-1} (Figure 1). With the CVC tip below the SVC/RA junction, the overshoot P wave was defined when the amplitude of the P wave abruptly increased in both directions exceeding the amplitude of QRS wave (Figure 1). While withdrawing the CVC, we verified whether the P wave appeared to have a normal size and shape compared with the P wave of conventional lead II. A normally-shaped P wave was defined by consensus between at least two of the three attending anesthesiologists. On the ECG tracing print, the vertical distances from the SVC/RA junction to the CVC tip were calculated to the nearest 1-cm interval, and were recorded at each display of the normally-shaped P wave, the tallest peaked P wave, the characteristic biphasic P wave and the overshoot P wave. Zero position referred to localization at the SVC/RA junction. Positive values refer to positions in the SVC above the SVC/RA junction, and negative values to positions in the RA below it.

Statistical analysis

As this was an observational study, formal sample size calculations were not undertaken. The CVC depths according to the characteristic P waves were compared using the Kruskal–Wallis test with Dunn's multiple comparison. SPSS software (version 11.0; SPSS Inc, Chicago, IL, USA) was used for all comparisons. Data

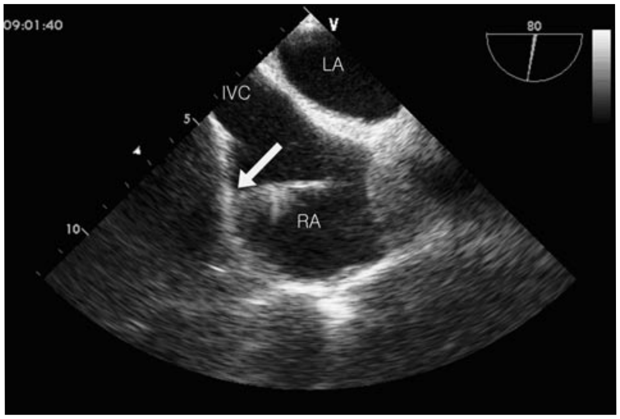

FIGURE 3 Overshoot P waves appeared when the central venous catheter tip (arrow) was contacting or in close proximity to the wall of the right atrium (RA) on transesophageal echocardiography. IVC = inferior vena cava, LA = left atrium.

are reported either as mean ± SD (range) or as median [interquartile range (range)]. A $P < 0.05$ was considered statistically significant.

Results

A total of 54 ECG-guided central venous catheterizations were studied in 42 men and 12 women: age, 52 ± 13 (20–73) yr; height, 160 ± 7 (145–176) cm; and weight, 57 ± 9 (42–89) kg. The operations were as follows: three abdominal cancer surgeries; one thoracic cancer surgery, 40 coronary bypass grafts, four aortic reconstructive surgeries, and six other forms of cardiac surgeries. There were no complications related to central venous catheterization. There were no patients in whom the CVC was directed to a vein other than the SVC and RA.

The tallest peaked P waves (n = 54) {median (interquartile range) [range]} were observed when the CVC tips were located at 0.0 cm (-1.0 to 0.0) [-3.0 to 0.0] below the SVC/RA junction. The P wave {median (interquartile range) [range]} returned to the normal upright configuration 4.0 cm (3.0 to 4.0) [2.0 to 5.0] above the SVC/RA junction (Figure 2).

As the CVC tips were advanced into the RA, characteristic biphasic P waves (n = 26) and overshoot P waves (n = 22) were observed at -4.0 cm (-5.0 to -3.0) [-5.0 to -2.0] and at -4.0 cm (-5.0 to -3.0) [-5.0 to -2.0] below the SVC/RA junction, respectively. When the overshoot P wave appeared, the TEE findings showed that CVC tips were making contact or in close proximity to the RA wall (Figure 3). When the CVC was rotated, in five cases the overshoot P wave disappeared, returning to the characteristic biphasic P wave and in 17 cases the overshoot P wave continued (Figure 1). In six cases (11%), however, only small peaked P waves were observed, without showing a characteristic biphasic P wave or an overshoot P wave until the CVC tip was advanced to a point 5 cm below the SVC/RA junction. Characteristic biphasic P waves were not obtainable in 23 of 54 patients (43%). The CVC depths between characteristic biphasic P waves (n = 26) and overshoot P waves (n = 22) were not different (Figure 2).

Discussion

In this study, after the SVC/RA junction was confirmed by TEE, characteristic P waves were displayed during ECG-guided central venous catheterization. The tallest peaked P waves, seemingly normal P waves, and a biphasic P wave pattern including characteristic and overshoot P waves, were displayed when the CVC tips were located at the SVC/RA junction, in the mid to upper SVC region and in the RA, respectively.

Analysis of P wave morphology as a marker ECG-guided central venous catheterization has been evaluated previously. However, most of these studies report variable results, and do not include clear anatomical correlates. In a study by McGee *et al.*,[10] the point of maximal P wave amplitude was presumed to be the catheter tip position closest to the sinoatrial (SA) node and the catheter was subsequently withdrawn 3 cm to locate the tip just proximal to the SVC/RA junction. In a study by Madan *et al.*,[7] after the biphasic P wave had been observed, the catheter was withdrawn to obtain a peaked P wave to position the CVC tip in the lower SVC. In another study by Wilson *et al.*,[6] after obtaining a biphasic P wave (defined as that measured when the catheter tip was opposite the SA node), the catheter was withdrawn until the P wave configuration changed to a peaked wave. In the study by Salmela *et al.*,[11] after an augmented peaked P wave was observed (indicating that the tip of the CVC lay in the RA), the catheter was slowly withdrawn until the P wave began to diminish, and then withdrawn another 1–2 cm to lie in the SVC. Other investigators have recommended that to locate the CVC tip within the SVC,[14–17] the CVC catheter should be withdrawn gradually to the point at which the P wave is normalized, after a peaked P wave has been obtained.

Inconsistency in ECG-guided central venous catheterization and interpretations may be caused by the technical difficulty in evaluating the exact location of the CVC tip. In previous studies, the location of the CVC was confirmed by chest *x-ray* (CXR).[5,6,11,14] Because a radiological definition of ideal location is not established, postoperative radiological evaluation may not have been performed accurately. On CXR, an apparent intersection of the SVC with the right superior heart border is often created by the left atrium instead of the RA.[18] The relative location of the CVC compared with the RA/SVC junction tends to appear deeper than the actual location when using a portable anterior–posterior CXR.[18] Furthermore, the position of the CVC tip may change during radiographic preparation because it may be displaced up to 1.5 to 3.0 cm with flexion and extension of the neck.[19] In addition, radiological interpretations are often imprecise and subject to inter-observer variability, because different radiographic landmarks are used.[6,10,20] However, the results for the tallest peaked P wave are consistent with previous studies using TEE[12,17,21] or direct confirmation at the operating field.[14] In this study, we believe that TEE facilitated assessment of CVC tip localization using a three-dimensional assessment of their positions.

Unsuccessful experiences have been reported when the CVCs are either too short, or form a loop.[11] False negatives have been observed in patients with cardiac pacemakers, and those with cardiomyopathic dilatation or atrial fibrillation.[5,11] If the CVC tip enters the internal jugular vein, the opposite subclavian vein, or the internal mammary vein,[5,7] the ECG pattern is attenuated, and the P wave will not show any marked negative deflection with a subsequent biphasic pattern as CVCs are advanced: this occurred in 18 of 1,236 cases studied.[5] In our study, when an overshoot P wave appeared, the characteristic biphasic P wave could be obtained by rotating the CVC in five of 22 patients. Although not characteristic, the overshoot P wave also has negative and later positive deflections, and can therefore be regarded as a type of biphasic P wave. However, such biphasic P wave patterns, including the characteristic and overshoot P waves, were not obtained in six of 54 patients. We do not know the exact causes, but one factor may have been a study population of primarily cardiac surgery patients, frequently with large RAs. Although we excluded patients with abnormal P waves, one limitation of this study is that 46 of the 54 patients enrolled were cardiac surgery patients, whose hearts were not normal.

During ECG-guided central venous catheterization, the biphasic P wave may be used to place the CVC tip in the RA. However, the characteristic biphasic P wave may not be obtained when the CVC tip is contacting or in close proximity to the RA wall. Although the overshoot P wave can be used to guide the CVC into the RA because the overshoot P wave is also biphasic, the CVC tip should not be located where the overshoot P wave is shown. The possibility of RA perforation may exist because of the fact that an overshoot P wave was observed only when CVC tips were making contact or in close proximity to the RA wall on TEE.

In a previous report,[22] the mean SVC length *in vivo* was approximately 6 cm with almost half the SVC within the pericardium. Therefore, a normally-shaped P wave, which can be obtained from about 4.0 cm above the SVC/RA junction, can be used to guide the CVC tip at the mid to upper SVC, preventing the possibility of cardiac tamponade caused by CVC. However, if avoiding upper SVC positioning for a potential risk of thrombosis, the operator may use a small peaked P wave as a guide to locate the CVC tip in the lower SVC.

In conclusion, during ECG-guided central venous catheterization, the tallest peaked P wave may be used to place the CVC tip at the SVC/RA junction, the normally-shaped P wave identifies the mid to upper SVC, and a biphasic pattern of the P wave can be used to locate the RA.

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