Netherlands Journal of Critical Care
Submitted March 2019; Accepted June 2019

ORIGINAL ARTICLE

POCUS series: The use of velocity time integral in assessing cardiac output and fluid responsiveness

J.E. López Matta[1,3], C.V. Elzo Kraemer[1,3], P.R. Tuinman[2,3], D.J. van Westerloo[1,3]
[1]Department of Intensive Care, Leiden University Medical Center, Leiden University, Leiden, the Netherlands
[2]Department of Intensive Care, Amsterdam UMC, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands
[3]Amsterdam Leiden Intensive care Focused Echography (ALIFE)

Correspondence
D. van Westerloo - djvanwesterloo@lumc.nl

Keywords - **ultrasound, cardiac output, POCUS, VTI**

Abstract
In the last decade ultrasound has found its place in the intensive care unit. Initially ultrasound was used primarily to increase safety and efficacy of line insertion but now many intensivists use point-of-care ultrasound (POCUS) to aid in diagnosis, assessment of therapy and therapeutic interventions. In this series we aim to highlight one specific POCUS technique at a time, which we believe will prove to be useful in your clinical practice. Our aim is to provide you with a short and practical description of the technique as well as its merits and pitfalls. In this issue we describe the use of the left ventricular outflow tract velocity time integral to ascertain cardiac output and fluid responsiveness.

Velocity time integral to measure cardiac output
Cardiac output assessment is an essential tool in critical care. One of the available noninvasive options to measure cardiac output is by using ultrasound. The most widely accepted and easily applicable method is to measure the left ventricular outflow tract (LVOT) diameter and combine this with flow velocity estimation using pulsed-wave Doppler.[1,2] The velocity time integral (VTI) is the stroke distance of blood during systole (cm) combined with the LVOT cross-sectional area (cm^2). The LVOT diameter (cm) is measured at the insertion of the aortic valves at systole in the parasternal long axis view and the aortic valve area is calculated by the formula Π x (**diameter** LVOT/2)² /4. Finally, to obtain the cardiac output this product is multiplied by the heart rate.[1] Measurement inaccuracies in measuring the LVOT diameter cause great variation in cardiac output results given that any error in diameter measurement will be squared when computing the cross-sectional area. This results in overestimation or underestimation of the stroke volume.[3] However, the LVOT diameter is very stable throughout the cardiac cycle which means aortic VTI variations are proportional to stroke volume variation, so that the VTI is an excellent surrogate marker for stroke volume and cardiac output.[3] From the A4C view, the apical five-chamber view is obtained by tilting the ultrasound beam anteriorly until the LVOT, aortic valve and the proximal ascending aorta come into view *(figure 1)*. If this view is obtained, the pulse-wave Doppler is placed in the LVOT just proximal to the aortic valve. The Doppler wave formed is frozen and the downsloping envelope is traced *(figure 2)*. Finally, the LVOT VTI may be measured in cardiac output assessment on your ultrasound machine. VTI in normal adults at rest is usually in the range of 18-22 cm, values below this reflect a decreased cardiac output.[3]

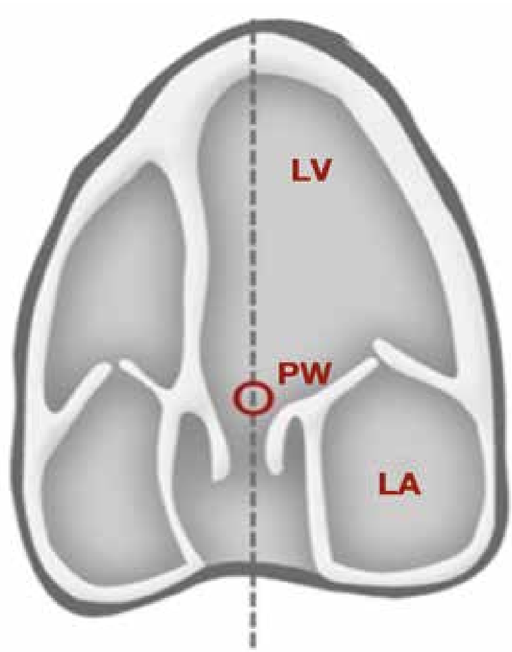

Figure 1. An apical five-chamber view is shown. Placement of pulse-wave Doppler (PW) in the LVOT is indicated. LA = left atrium, LV = left ventricle

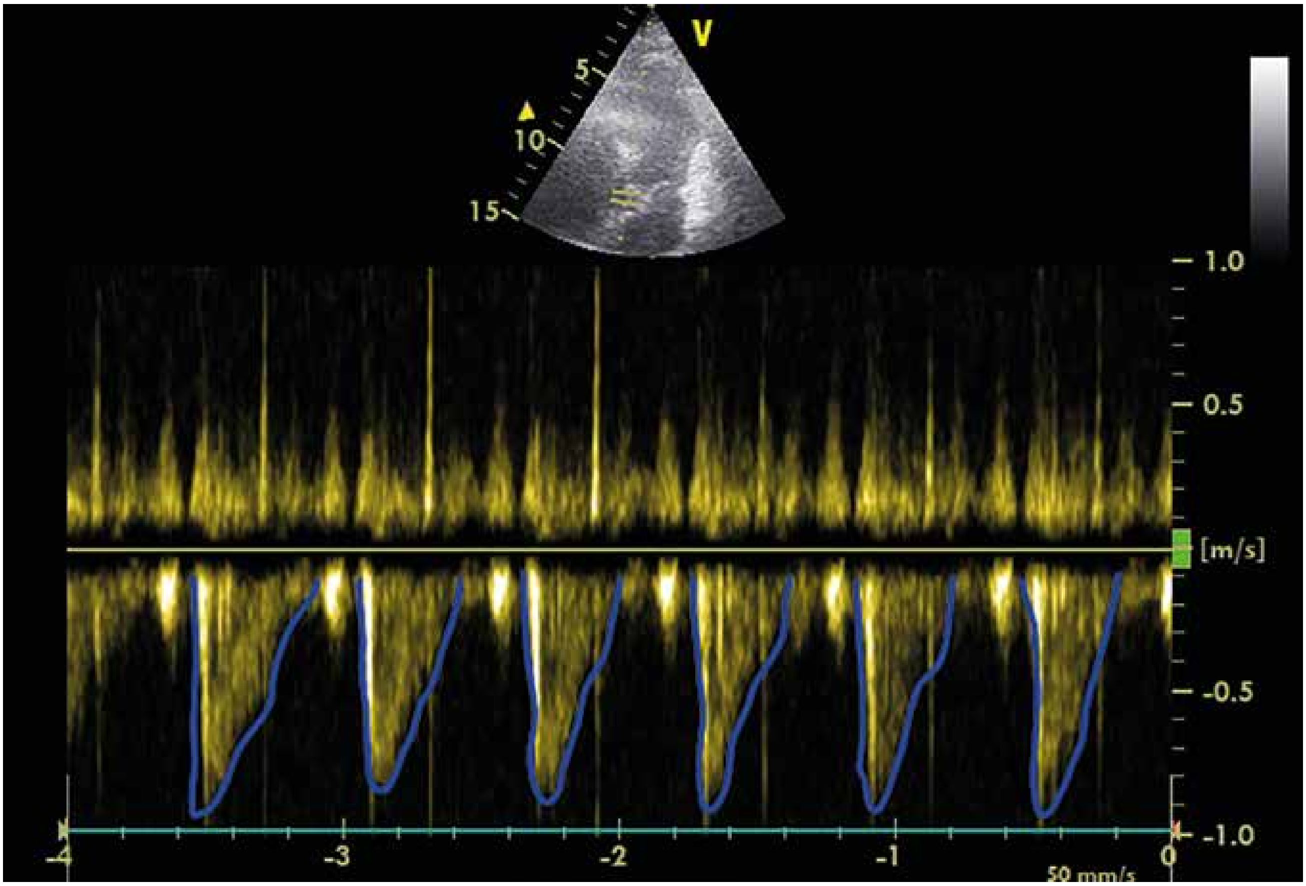

Figure 2. Pulse-wave Doppler and correct selection of downward sloping curves is shown

Velocity time integral to predict fluid responsiveness

Mounting evidence suggests that excessive fluid administration is harmful. It is therefore important to define which patients will benefit from fluids with an increase in cardiac output and which patients will not.[4] POCUS may be used to guide fluid therapy by evaluating the lung for the presence of B lines and by measuring the collapsibility of the inferior vena cava.[5] Especially this last method, however, has been shown to be very unreliable, particularly in spontaneously breathing patients.[6] In contrast, VTI measurements coupled with a fluid challenge or the passive leg raising test allows us to assess for true fluid responsiveness.[7]

The quantity of a fluid challenge may span from a mini fluid challenge of 100 ml to the classic fluid challenge of 500 ml.[8] Another way to test for fluid responsiveness is by using the passive leg raising test.[9] With this method about 300 ml of blood is mobilised from the venous system towards the general circulation immediately increasing venous return and stroke volume.[10] Please be advised that it is far better to tilt the bed than to manually lift the legs since the latter method may result in sympathetic activation which significantly hampers a proper interpretation of the effects of the leg raise. An increase of VTI of 12% or more correlates well with fluid responsiveness.[11] Cut-off values for conventional fluid challenges are an increase in VTI of 10% for a mini-challenge (100 ml) and 15% with a 500 ml fluid challenge.[12,13] Consequently fluid suppletion should not be given if the VTI is not significantly increased after a fluid challenge.

Thermodilution methods and pulse contour methods have been developed to evaluate fluid responsiveness as well. In contrast to pulse contour methods the estimation of VTI is reliable in spontaneously breathing patients. Furthermore, haemodynamic monitoring using thermodilution is more invasive and of limited use in specific groups. For example, thermodilution is inaccurate in patients on extracorporeal membrane oxygenation (ECMO) since the redistribution of blood flow into the ECMO system causes inaccuracies in the thermodilution measurements.[14] Echocardiographic measurements such as VTI do not vary under ECMO support, making it an ideal tool for haemodynamic monitoring in this group of patients.[15]

Limitations

Aortic stenosis or subvalvular obstruction (either structural as in hypertrophic cardiomyopathy or dynamic as in sepsis and underfilling) impacts on the measurement of the VTI by generating suspiciously high flows and in these cases VTI is an inaccurate surrogate for the actual cardiac output.[11] Equally, patients in atrial fibrillation might have varying degrees of flow velocities with every stroke. During atrial fibrillation it is therefore advisable to measure a larger number of aortic VTI curves (>10) to get a more accurate average.[16] Finally, VTI may be overestimated in aortic regurgitation because the regurgitant diastolic flow is not taken into consideration.[17]

Obtaining a A4C view in a ICU patient can be challenging, especially because most of the patients cannot simply lie on their left flank. In cases where the optimal image is not possible in supine position, one can rotate the bed to the left on its central axis, this way tilting the whole body in the same direction. In many cases this position change is enough to optimise the image.

Instructions for the measurement of VTI

An instructional video accompanies this article:
https://www.njcc.nl/njcc-video

1. Use a phased-array probe and obtain an apical five-chamber view at the apex.
2. Place the pulse-wave Doppler marker just under the aortic valve.
3. Be careful that the line of the Doppler gate does not differ too much with the direction of the outflow tract (<20 degrees). This is best obtained in a well-oriented apical view with the septum vertical, aortic valve planes horizontal and apex down in the middle of your image.
4. Record the blood flow velocity at this point and freeze the image *(figure 2)*.
5. Go to LVOT VTI (cardiac output) measurement on your ultrasound machine. Trace the envelope of maximal velocity in three to five consecutive velocities. Calculate the average VTI *(figure 2)*.

Conclusion

The simplicity and accuracy of VTI measurement using POCUS makes it an ideal noninvasive tool to measure cardiac output and predict fluid responsiveness in the critically ill.

Disclosures

All authors declare no conflict of interest. No funding or financial support was received.

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