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VIEWPOINT

How to calculate ventricular–arterial coupling?

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Ventricular–arterial coupling (VAC) is a very interesting variable in the field of heart failure (HF), enabling a more in-depth evaluation of patient profile. Indeed, 'vascular' scenarios have been mentioned for years as an important entity within the scope of HF, yet without any practical approach to efficiently identify them. The assessment of VAC can fill in this gap.

A consensus document was published in the *European Journal of Heart Failure* in April 2019 presenting the assessment, clinical implications and therapeutic perspectives related to VAC in a clinical HF setting.[1] To show the clinical usefulness of VAC, this viewpoint presents the assessment of VAC in various clinical scenarios such as systemic hypertension and HF with reduced (HFrEF) and preserved ejection fraction (HFpEF), respectively. In order to facilitate the utilization of VAC into everyday clinical practice, a simplifying Excel sheet for the VAC calculation is provided (online supplementary *Appendix S1*).

The interplay between the heart and the arterial system has recently gained much attention since interventions that improve both myocardial and vascular functions may delay the progression to HF, valvular heart disease and possibly even improve prognosis.[1,2] Today, the assessment of VAC in clinical practice is being facilitated by advances in non-invasive assessment of cardiac imaging. Traditionally, VAC has been defined as the combined marker of arterial and myocardial function, expressed as E_a/E_{es} ratio, where E_a reflects arterial elastance (an index of arterial load on the left ventricle) and E_{es} ventricular elastance (an index of the contractility of the left ventricle).[3] The E_a/E_{es} ratio has shown to be a key determinant of HF and increased arterial stiffness, both independently associated with impaired microcirculation causing damage to the end organs such as the kidneys.

Arterial elastance (E_a) is defined as the ratio of end-systolic pressure and stroke volume (ESP/SV)[4] which is influenced by the vascular resistance, pulsatile load and heart rate. In contrast, E_{es} is a load-independent measure of left ventricular (LV) contractility and reflects the slope of the end-systolic pressure–volume relationship, originated from the principles of pressure–volume curve as the ratio of ESP and end-systolic volume (ESP/ESV).[5] Subsequently, E_a/E_{es} (ESP/SV)/(ESP/ESVi) can be further simplified as ESV/SV, after removing ESP in the equation. E_{es} is affected by LV chamber stiffness and geometry and has an inverse correlation with LV mass.

In order to calculate E_{es}, invasive multi-beat intraventricular catheterization has been regarded as the gold standard method. However, the non-invasive method by Chen *et al.*[3] is commonly used where E_{es} can be calculated by the formula: $E_{es} = [DBP - (End(est) \times SBP \times 0.9)]/End(est) \times SV$ where DBP and SBP are diastolic and systolic arm-cuff blood pressures, End(est) is the estimated normalized ventricular elastance at the onset of ejection, and SV is Doppler-derived SV (*Figure 1*).

To elicit VAC results in routine practice, this viewpoint presents the assessment of VAC in various archetypal clinical scenarios such as systemic hypertension and HFrEF and HFpEF. We hope these examples will promote the use of this formula among physicians managing patients with HF. In addition, an Excel sheet providing embedded calculations is provided in online supplementary Appendix S1. Within routine care, physicians will only have to enter key variables from their echocardiographic exams (namely SBP, DBP, LV ejection fraction, stroke volume, pre-ejection time and ejection time) and the sheet will provide correct calculations of E_{es}, E_a and VAC. This simplified sheet is more easily usable that the previous iOS-based VAC calculators (iElastance); it reaches a wider audience as it is not tied to a platform/operating system and also allows decimals for the included variables.[6]

Previous studies have shown that the optimal value of VAC derived from the E_a/E_{es} ratio should range from 0.5 to 1 reflecting the state when the stroke work of left ventricle is ideal.[7,8] Patient 1 (*Figure 1*) consequently corresponds to a 'normal' situation, as both blood pressure, ejection fraction, SV, and their interplay are within normal range.

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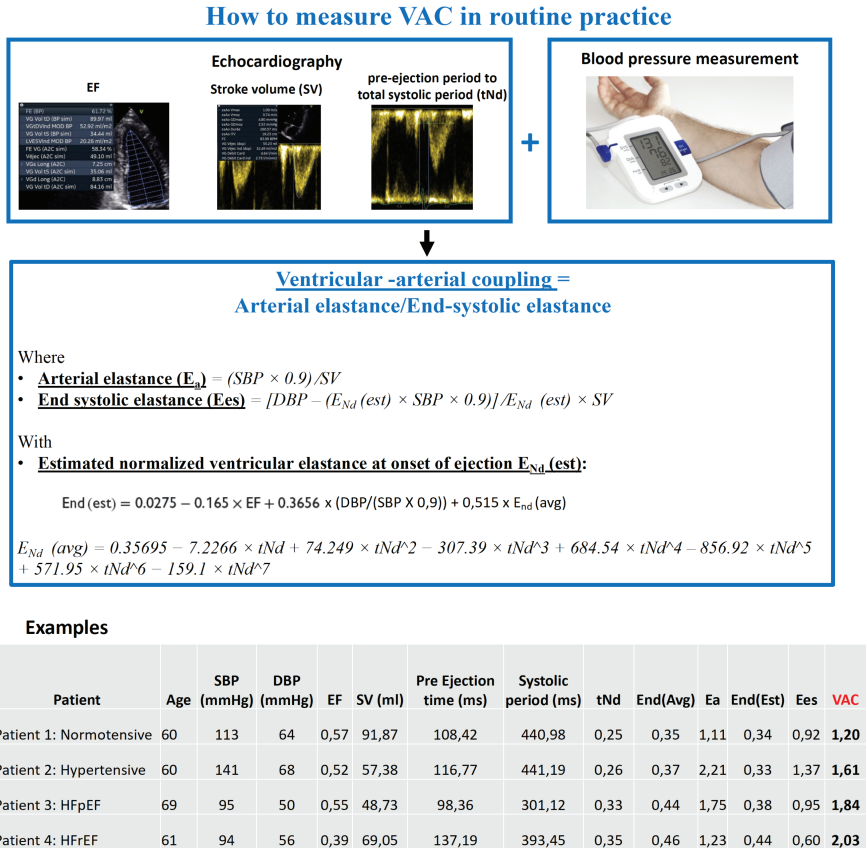

Examples

Patient	Age	SBP (mmHg)	DBP (mmHg)	EF	SV (ml)	Pre Ejection time (ms)	Systolic period (ms)	tNd	End(Avg)	Ea	End(Est)	Ees	VAC
Patient 1: Normotensive	60	113	64	0,57	91,87	108,42	440,98	0,25	0,35	1,11	0,34	0,92	**1,20**
Patient 2: Hypertensive	60	141	68	0,52	57,38	116,77	441,19	0,26	0,37	2,21	0,33	1,37	**1,61**
Patient 3: HFpEF	69	95	50	0,55	48,73	98,36	301,12	0,33	0,44	1,75	0,38	0,95	**1,84**
Patient 4: HFrEF	61	94	56	0,39	69,05	137,19	393,45	0,35	0,46	1,23	0,44	0,60	**2,03**

Figure 1 How to measure ventricular–arterial coupling (VAC) in routine practice. DBP, diastolic blood pressure; Ea, arterial elastance; Ees, ventricular elastance; EF, ejection fraction; HFpEF, heart failure with preserved ejection fraction; HFrEF, heart failure with reduced ejection fraction; SBP, systolic blood pressure; SV, stroke volume from four cavities pulsed Doppler; tNd, ratio of the pre-ejection period to the total systolic period measured on the aortic pulse Doppler.

When arterial load (E_a) increases to the point when $E_a/E_{es} > 1$, a VAC mismatch appears with subsequent lower LV contractile efficiency.[9] This mismatch in VAC is often seen as the effect of increasing age and development of hypertension. Yet, the increase of E_a is met by a simultaneous increase of E_{es} (i.e. LV contractility) which preserves the VAC despite the presence of hypertension observed in patient 2. It should be acknowledged that E_a/E_{es} ratio has some limitations, i.e. it does not characterize the LV loading sequence.[10] Also, in HFpEF, it may be normal because both E_a and E_{es} are increased (patient 3). In the example of patient 4 with HFrEF, E_{es} is decreased as expected whilst E_a is slightly increased resulting in $E_a/E_{es} \geq 2$. We would consequently like to emphasize that the use of the pulse wave velocity/global longitudinal strain (PWV/GLS) ratio may be more appropriate in a number of settings to characterize VAC since it incorporates the gold standard methods to assess arterial load (PWV) and LV contractility (GLS). Importantly, PWV/GLS has been shown to be better correlated with subclinical target organ damage compared with the traditional echocardiographic method (E_a/E_{es}).[11] Further, PWV/GLS might also help predicting response to cardiac resynchronization therapy and the benefit from sodium–glucose cotransporter 1 inhibitor, glucagon-like peptide-1 receptor agonists and anti-inflammatory treatment in patients with rheumatoid arthritis.[12–14] Yet, even if PWV/GLS is likely more appropriate in a research setting, we can already use VAC in routine practice, only using simple echocardiographic measurements.

We hope that the figure presented herein (along with the provided online calculator, https://cic-p-nancy.fr/vac-calculation-tool-sharing/) will promote the adequate calculation of the E_a/E_{es} ratio and prompt the use of VAC in patients with HF.

Supplementary Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Conflict of interest: none declared.

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