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Non-invasive assessment of ventricular-arterial coupling: correlation between myocardial work and the pulse wave velocity parameters

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SOUHRN

Úvod: Měření práce myokardu (myocardial work, MW) představuje novou echokardiografickou metodu založenou na sledování smyčky tlak-deformace srdeční komory, což umožňuje kvantifikovat výkonnost srdce. Na druhé straně rychlost pulsní vlny (pulse wave velocity, PWV) určuje tuhost tepen na základě poznatku, že se zvyšující se tuhostí tepny se zvyšuje i rychlost anterográdního a retrográdního přenosu sfygmické vlny.
Cíl: Cílem této studie bylo stanovit korelaci mezi parametry MW a PWV.
Metody: Do studie jsme zařazovali všechny po sobě následující pacienty bez kardiovaskulárního onemocnění, kteří v období mezi červnem 2021 a červencem 2022 absolvovali transtorakální dopplerovské echokardiografické vyšetření. Hodnoty MW byly vypočítány ze smyčky tlak-deformace srdeční komory, do níž byly začleněny hodnoty neinvazivního vyšetření tepenného tlaku podle doporučení pro standardní echokardiogracfické vyšetření metodou „speckle tracking". Hodnota PWV se měřila tonometrem na úrovni společné karotidy a společné femorální tepny.
Výsledky: Celkem bylo do studie zařazeno 66 pacientů průměrného věku 30,7 ± 8,6 roku. Byla nalezena statisticky významná negativní korelace mezi PWV a celkovou zbytečně vynaloženou energií (global wasted energy, GWE) (r = –0,317; p < 0,01) při korelaci s celkovou zbytečně vynaloženou prací (global wasted work, GWW) (r = 0,324; p < 0,01). Statisticky významná korelace přetrvávala v podskupinách žen i mužů u GWE (ženy: r = –0,280; p < 0,05; muži: r = –0,362; p < 0,05) i u GWW (ženy: r = 0,359; p < 0,05; muži: r = 0,359; p < 0,05).
Závěr: Vztah mezi MW a PWV jako projev součinnosti mezi levou komorou a velkými tepnami může potenciálně představovat užitečný nástroj pro časné odhalení subklinické dysfunkce kardiovaskulárního systému.

ABSTRACT

Introduction: The myocardial work (MW) is a new echocardiographic method, based on the pressure-strain loop, which allows quantifying the cardiac performance. On the other hand, the pulse wave velocity (PWV) evaluates arterial stiffness, knowing that as the stiffness of an artery increases, the transmission velocity of the anterograde and the retrograde sphygmic wave increases.

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Keywords:
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Stiffness
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Purpose: The aim of the study is to evaluate the correlation between MW and PWV parameters.
Methods: We enrolled consecutively all patients without cardiovascular disease who underwent transthoracic Doppler echocardiography between June 2021 and July 2022. The MW parameters were derived from the strain-pressure loop, including in its calculation the measurement non-invasive arterial pressure, according to standard speckle tracking echocardiography recommendations. The PWV measurement was obtained by tonometry at the level of the common carotid artery and the common femoral artery.
Results: We enrolled 66 patients (mean age: 30.7±8.6 years). There was a significant inversely proportional correlation between PWV and GWE (r = –0.317; p <0.01) meanwhile there was a directly proportional correlation with GWW (r = 0.324; p <0.01). The statistically significant correlation remained in the female and male subgroups for GWE (female: r = –0.280; p <0.05; male: r = –0.362; p <0.05) and GWW (female: r = 0.359; p <0.05; male: r = 0.359; p <0.05).
Conclusion: The relationship between MW and PWV as a demonstration of ventricular arterial coupling may potentially be a useful tool in the early recognition of subclinical cardiovascular dysfunction.

Introduction

Cardiovascular disease is the leading cause of the global burden of morbidity and mortality. The latest evidence has shown that to anticipate atherosclerosis there are other phenomena involving the remodeling of the arteries such as increased thickness and stiffness: the “arteriosclerosis”. Vessel remodeling is a pathophysiological process that occurs with advancing age.[1] However, although the classic cardiovascular risk factors – smoking, hypertension, diabetes, dyslipidemia, obesity - may be a factor accelerating arteriosclerosis, vessel remodeling now seems to be confirmed as an independent risk factor for future cardiovascular events and all causes of mortality.[2,3]

In the evaluation of arterial stiffness as an independent risk factor, it would be interesting to evaluate together the performance data of the left ventricle as a constitutive element of the ventricular-arterial coupling (VAC).[4]

VAC is defined as the interaction of the heart with the systemic circulation, playing a key role in cardiovascular performance, influencing both the magnitude and efficiency of left ventricular (LV) stroke work transfer to the circulation.[5]

In deed, it is well known how heart and vessels are mutually influenced and the deterioration of the function of one affects the other.[6,7]

In optimal coupling conditions, in fact, a maximum cardiac work, efficiency, of the left ventricle is achieved while maintaining arterial pressure values in the normal range.

The assessment of arterial stiffness is obtained by measuring the velocity of the anterograde aortic sphygmic wave (PWV) with tonometry, regarded as the gold standard.[8]

Among the devices currently in use for the assessment of arterial stiffness, the SphygmoCor Xcel system (AtCor Medical, Sydney, NSW, Australia) is a well-validated and widely used device.[9]

The SphygmoCor Xcel device measures Augmentation Index using a partially inflated brachial cuff and PWV using a partially inflated femoral cuff together with carotid applanation tonometry.

The non-invasive myocardial work (MW) is a newly implemented tool that evaluates global and regional myocardial performance derived from the non-invasive stress-pressure loop. This measurement is obtained from 2D strain data and non-invasive brachial artery pressure, being less dependent of preload and afterload.[10]

The aim of our study was to assess in healthy patients the PWV and the MW indices as the evaluation of the ventricular-artery coupling.

Methods

Study population

We enrolled consecutively outpatients who underwent transthoracic Doppler echocardiography (TTE) in the Echo-lab of Cardiology Institute of the Policlinico Universitario “G. Martino” of Messina between June 2021 and July 2022.

We included patients older than 18 years in the study and we excluded patients suffering from cardiovascular disease (CVD) and cardiovascular risk factors or poor acoustic window. All patients underwent cardiological examination, electrocardiogram, and complete echocardiogram colour-Doppler with the assessment of 2D strain, MW indices and PWV analysis. The Institutional Review Board of Policlinico Universitario “G. Martino” approved the study. Our study complies with the Helsinki declaration for investigations in human patients.

Cardiovascular disease and risk factors definition

CVD and risk factors were defined according to Guidelines on Cardiovascular Disease Prevention of the European Society of Cardiology.

CVD included previous acute myocardial infarction, acute coronary syndrome, coronary revascularization and other arterial revascularization procedures, stroke and transient ischemic attack, aortic aneurysm, peripheral artery disease, cardiomyopathies and genetic syndromes. It does not include some increase in continuous imaging parameters such as intima-media thickness of the carotid artery. Risk factors for CVD included: family history of premature CVD, smoking, arterial hypertension, diabetes mellitus, raised lipid level, obesity and chronic kidney disease.

Pulse wave velocity analysis

PWV analysis was performed with SphygmoCor XCEL System v1 technology (AtCor Medical Pty Ltd., Sydney, Australia) and software (SphygmoCor XCEL Software Version: 1.2). PWV analysis was performed according to the consensus document and measurement was performed at the level of the right carotid artery and right femoral artery. Measurement sites for the PWV analysis were the right carotid artery and right femoral artery.[8] We marked the level where the carotid pulse was strongest, and a femoral cuff was placed at the level of the right thigh. The distance between the carotid artery mark and the upper edge of the femoral cuff was recorded into the SphygmoCor software. The 'femoral to cuff' length is automatically subtracted from the 'carotid to cuff' length to indicate the carotid-femoral distance which is used in the PWV calculation.

The brachial blood pressure was registered, and the time of the acquisition was chosen in the SphygmoCor software. For standardisation of registrations the device was placed on the marked carotid artery position, configured to record automatically and the pulse wave was recorded after high quality waveforms during the specified capture time.

The measurement quality was assessed automatically by the SphygmoCor software (based on consistent pulse peaks, troughs and amplitude), and were indicated with either a green "quality controlled" tick, or a red cross indicating a lower quality measure.[11] All data for inclusion in this research project were required to have a quality-controlled tick.

Echocardiographic analysis

Images were acquired with resting patients in the left lateral decubitus position with a commercially available ultrasound system in the parasternal and apical views (Vivid E9 and E95, GE Vingmed Ultrasound, Horten, Norway). M-mode and 2D, colour, pulsed wave and continuous wave Doppler images were obtained. Data were analysed offline using EchoPAC version 204 software (GE Vingmed Ultrasound, Horten, Norway). LV end-diastolic volume (LVEDV), LV end-systolic volume and LV ejection fraction (LVEF) were assessed in apical four- and two-chamber views using Simpson's biplane method.[12] In order to assess LV global longitudinal strain (GLS), 2D-speckle tracking analyses were carried out offline in images acquired from apical views at four, two and three axes as previously described.[13]

Myocardial work analysis

The LVMW calculation from non-invasive LV pressure–strain analysis has been described previously.[10,14] LVMW indices were computed with the latest vendor-specific module (EchoPAC version 204 software, GE Medical Systems, Horten, Norway) combining LV GLS and a noninvasively measured blood pressure. LV GLS was evaluated with 2D speckle tracking echocardiography drawing manually the endocardial rim in four-, two-, and long-axis apical views. The non-invasive LV pressure curve was assessed by measuring the time of valvular events by echocardiography and adjusting the standard LV pressure curve to the duration of isovolumic contraction, LV ejection, and isovolumic relaxation. In order to calibrate the curve amplitude, blood pressure records from the patient's brachial cuff were recorded at baseline echocardiography and were used instead of the peak LV pressure. The software then processed a non-invasive LV pressure-strain curve using a combination of LV GLS data from the entire heart cycle and the instant LV pressure. Cardiac work was calculated as a function of time throughout the cardiac cycle. The following LVMW indices were derived: global work index (GWI) defined as total work within the area of the LV pressure–strain loops calculated from mitral valve closure to mitral valve opening; global constructive work (GCW) defined as work performed during shortening in systole adding work during lengthening in isovolumic relaxation; global wasted work (GWW) defined as work performed during lengthening in systole adding work performed during shortening in isovolumetric relaxation and global work efficiency (GWE) calculated as the sum of constructive work in all LV segments, divided by the sum of constructive and wasted work in all LV segments. GWI, GCW, and GWW were expressed as mmHg% and GWE as a percentage.[15]

Statistical analysis

Categorical data were summarized as percentages and continuous data as mean ± standard deviation (SD). T-test for independent samples was used to compare the means of continuous variables and χ^2 test for qualitative variables. We used the Kolmogorov–Smirnov test for normality in order to evaluate the assumption of t-test. The correlation between MW indices and PWV in the entire population and in subgroups according to gender was assessed using Spearman's rank correlation. A p value less than 0.05 was considered significant. All the statistical analyses were performed using IBM SPSS Statistics v26 software.

Results

Study population and clinical characteristics

In our study, 66 patients without cardiovascular disease were enrolled. The patients had a mean age of 30.73±8.56 years, body mass index (BMI) of 23.54±4.18 kg/m^2, body surface area (BSA) of 1.76±0.20 m^2, systolic blood pressure (SBP) 119.94±9.30 mmHg and diastolic blood pressure (DBP) 72.42±9.10 mmHg, as seen in Table 1. The patients had mean LVEF of 60.36±5.21 %, GLS –20.27±1.70%, GWI 1815±196.20 mmHg%, GCW 2171.45±255.52 mmHg%, GWE 95.82±1.39% and GWW 81.73±32.59 mmHg%, as seen in Table 2. In the comparison between the female and male subgroups, there were no statistically significant differences in clinical and echocardiographic characteristics, as reported in Tables 1 and 2.

Correlation between pulse wave velocity and myocardial work indices

Figure 1 shows the correlations of PWV with MW indices. There was a significant inversely proportional correlation between PWV and GWE (r = –0.317; p <0.01) meanwhile there was a directly proportional correlation with GWW (r = 0.324; p <0.01). GWI (r = 0.201; p = 0.16) and GCW (r = 0.236; p = 0.98) did not show a statistically significant correlation with PWV. The statistically significant correlation remained in the female and male subgroups for GWE (female: r = –0.280; p <0.05; male: r = –0.362; p <0.05) and

Table 1 – Baseline clinical characteristics of population

	All patients (66)	Female (22)	Male (44)	*p* value
Age, years	30.73±8.56	30.82±4.49	30.68±10.04	0.952
BSA	1.75±0.19	1.58±0.09	1.84±4.49	0.265
BMI	23.55±4.18	21.65±3.40	24.49±4.25	0.008
SAP, mmHg	119.94±9.92	116.00±7.67	121.91±10.41	0.021
DAP, mmHg	72.42±9.02	72.91±7.76	72.18±9.66	0.760
HR, bpm	69.97±12.51	76.73±12.17	66.59±11.37	0.001
Sex (male), %	66.7			

BMI – body mass index; BSA – body surface area; DAP – diastolic artery pressure; HR – heart rate; SAP – systolic artery pressure.

Table 2 – Echocardiographic characteristics of population

	All patients (66)	Female (22)	Male (44)	*p* value
FE, %	60.36±8.56	30.82±4.49	30.68±10.05	0.692
EDVi, mL/m²	50.67±10.45	47.30±10.19	52.34±10.28	0.64
ESVi, mL/m²	20.55±6.37	19.91±7.03	20.88±6.06	0.564
E/E'	6.08±2.67	5.44±1.07	6.52±3.32	0.193
S', cm/s	10.67±1.82	10.27±1.66	6.52±3.33	0.243
LAVi, mL/m²	15.24±10.46	14.25±9.72	15.73±10.88	0.592
PAPS, mmHg	21.57±5.70	21.60±5.14	21.56±6.13	0.985
GLS, %	–20.27±1.7	21.27±1.80	19.77±1.42	0.001
GWI, mmHg%	1815±196.20	1875±157.78	1785±208.02	0.079
GCW, mmHg%	2171.45±255.52	2268.27±213.26	2123.05±263.23	0.028
GWW, mmHg%	81.73±32.60	85.64±31.13	79.77±33.48	0.495
GWE, %	95.82±1.39	95.82±1.22	95.82±1.48	1.000
PWV, m/s	7.56±1.12	7.46±1.10	7.62±1.14	0.601
Pulse pressure, mmHg	34.09±8.18	30.27±5.18	36±8.76	0.006
AIX, %	16.15±15.05	18.27±18.11	15.09±13.36	0.422

AIX – central augmentation index; EDVi – end diastolic volume index; EF – ejection fraction; ESVi – end systolic volume index; GCW – global constructive work; GLS – global longitudinal strain; GWE – global work efficiency; GWI – global work index; GWW – global wasted work; LAVi – left atrial volume index; PAPS – pulmonary artery systolic pressure; PWV – pulse wave velocity.

GWW (female: r = 0.359; $p < 0.05$; male: r = 0.359; $p < 0.05$), as reported in Figure 2.

Discussion

The results obtained from our study confirm the close link between heart and vessels, but even more they show how through non-invasive methods it is possible to assess the status of one in relation to the other. MW in this scenario was found to be useful in assessing myocardial performance by demonstrating better sensitivity than traditional LV performance assessment methods.[10] GWW is a parameter that represents wasted work, a quota of work that does not contribute to the building of LV ejection. The increase in GWW can be caused by several scenarios, first ischemia, but also chronic damage or congenital alterations, or even in the context of hypertensive heart disease.[14]

The worsening of LV function can be recognized in an imbalance between GWW and GCW. GWE is the parameter that best describes the relationship between GCW and GWW and is expressed as a percentage.[16] A high value of efficiency is clear to indicate a maximal cardiac work in which the waste (GWW) is low. LV efficiency is therefore affected by increased outflow resistance, increased afterload and by arteriosclerosis.[6] In fact, in healthy subjects both parameters GWW and GWE correlated with PWV with high significance.

PWV is the speed of the anterograde sphygmic wave inside the vessel; it is generated by systole and ends with the end of the cardiac cycle: its propagation on the walls of the arteries generates many reflex waves that are added to the anterograde wave in the diastolic phase and lead to an increase in pressure in the peripheral territories.[17,18] The sum of these two wavefronts is assessed by the AI parameter. When arteriosclerosis is present, it is clear how both parameters (PWV and AI) are increment-

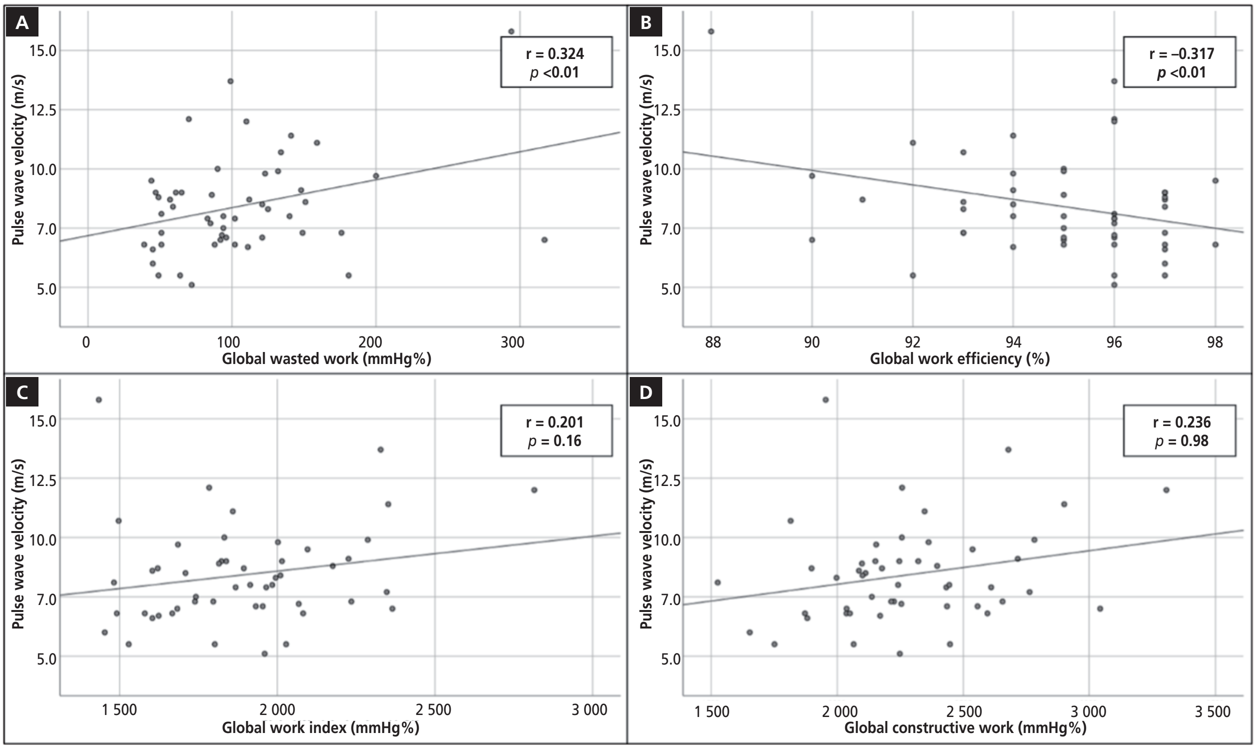

Fig. 1 – Scatterplot of the relationship between pulse wave velocity and GWW (A), GWE (B), GWI (C) and GCW (D).

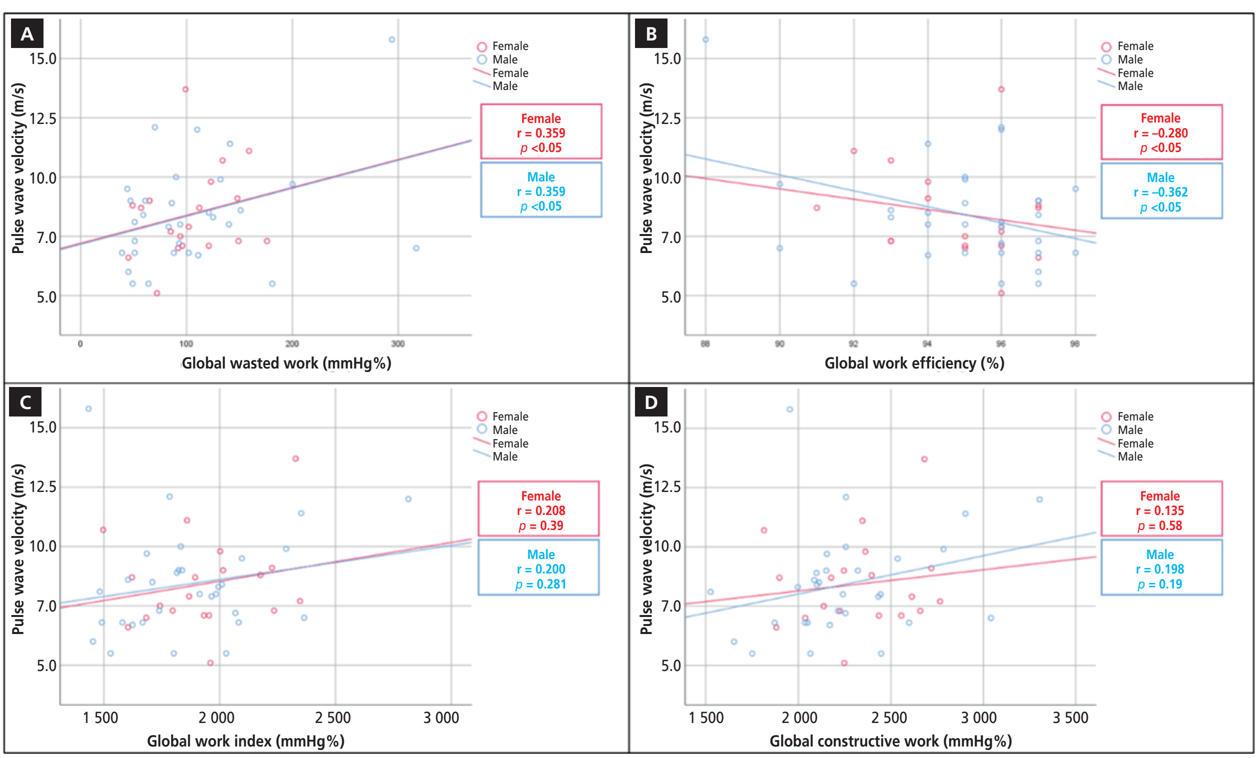

Fig. 2 – Scatterplot of the relationship between pulse wave velocity and GWW (A), GWE (B), GWI (C) and GCW (D) in female and male subgroups.

ed. Increased vessel resistance and decreased vessel distensibility can enhance sphygmic wave velocity, resulting in mistiming with the cardiac cycle, conflicting with the reflex waves just before the end of systole: as a result, the pressure rises in the systolic phase, leading to an afterload increase.[19]

The afterload causes an increase of the systolic pressure of the left ventricle; consequently we will have an increased wall stress that results in a worsening of the efficiency of the left ventricle and with the generation of wasted work. However, the same mechanism, resulting in increased afterload, leads to premature closure of the aortic valve, increasing the wasted work.[20]

Analyzing the function of the MW, the assessment of wasted work is provided by the deformation of the left ventricle following the closure of the aortic valve: fibre-shortening does not occur during systole but at its end ("post-systolic deformation").[14,21]

Our study also found the same correlation by analyzing both male and female groups.

In summary, VAC assessment represents a promising tool for early detection of cardiovascular disease. The MW and PWV are closely related, studying the correlation between them may reveal new perspectives in the detection of "primum movens" and in therapeutic management of cardiovascular disease. A larger study is required to prove VAC alteration in patients with risk factors or cardiovascular disease.

Conclusion

The relationship between MW and PWV as a demonstration of ventricular arterial coupling may potentially be a useful tool in the early recognition of cardiovascular dysfunction. Further studies will be needed to investigate the feasibility of these two methods in daily practice.

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