



Original

Association between dicrotic notch loss and arterial stiffness assessed by an oscillometric method

Pérdida de la escotadura dícrota como marcador de rigidez arterial comparado con un método oscilométrico

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Abstract

Introduction: arterial stiffness is associated with an increase in cardiovascular risk; thus, an accurate measurement can be useful in the clinical practice. The most used method is the measurement of the pulse wave velocity (PWV) however, it is unknown if there is an association of arterial stiffness with the loss of dicrotism by pulse volume recording (PVR).

Method: retrospective descriptive observational study based on records and manual data collection, with the aim of determining if there is a relationship between the increase in pulse wave velocity measured by Arteriography® and the loss of dicrotism in a thigh in patients treated at the Luis Felipe Gómez Isaza vascular laboratory, in the city of Medellín, Colombia.

Results: 160 patients were included, of which 52.5% were male and 43.8% were female. The mean ankle-brachial index was 0.98, mean arterial pressure was 105.9 mmHg. The median pulse velocity was 9.6 m/s and 37.5% of the patients did not have dicrotism. Regarding the analysis of speed and dicrotism, it was documented that the median PWV was higher in the absence of dicrotism with $p = 0.049$.

Conclusions: in patients with elevated PWV, loss of the dicrotic notch was more frequent, which confirms the hypothesis of PVR as a measure of arterial stiffness.

Keywords:

Arterial stiffness.
Cardiovascular
diseases. Pulse wave
analysis.

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Resumen

Introducción: la rigidez arterial está relacionada con un incremento en el riesgo cardiovascular, por lo que su determinación puede ser de utilidad para guiar decisiones clínicas. El método más utilizado es la medición de la velocidad de onda de pulso (VOP), pero se desconoce si hay una asociación entre la rigidez arterial y la pérdida de la escotadura dicrótica (ED) por análisis volumétrico de pletismografía arterial de miembros inferiores (AVP).

Metodología: estudio observacional descriptivo, retrospectivo y con intención analítica basado en registros y recolección manual de datos con el objetivo de determinar si existe relación entre el aumento de la velocidad de la onda de pulso medida por Arteriography® y la pérdida de la escotadura dicrótica en el muslo medida por análisis volumétrico por pletismografía arterial de miembros inferiores (AVP) en pacientes atendidos en el Laboratorio Vascular Luis Felipe Gómez Isaza, en la ciudad de Medellín (Colombia). Se evaluó la concordancia entre los expertos (interobservador) para la determinación de la pérdida de la escotadura dicrótica en las ondas de volumen mediante coeficiente kappa.

Resultados: se incluyeron 160 pacientes, de los que el 53,2 % fueron hombres y el 46,8 %, mujeres. La concordancia interobservador entre los expertos fue moderada entre los observadores 1 y 2 y sustancial entre los observadores 1 y 3, así como en el 2 y en el 3 (kappa entre 0,4 y 1,0). El índice tobillo-brazo promedio fue de 0,98 y la presión arterial media promedio fue de 105,9 mmHg. La mediana de la velocidad de onda de pulso fue 9,25 m/s (RIQ: 7,9-10,6 m/s) y el 37,5 % de los pacientes no tenía escotadura dicrótica en el muslo. En cuanto al análisis de velocidad y dicrotismo, se documentó que la mediana de VOP es mayor en ausencia de escotadura dicrótica, con una $p = 0,0025$.

Conclusiones: en pacientes con VOP elevada se documentó pérdida de la escotadura dicrótica con mayor frecuencia, lo que apoya la hipótesis de la AVP como medida de rigidez arterial.

Palabras clave:

Rigidez arterial.
Enfermedades
cardiovasculares.
Análisis de onda
de pulso.

INTRODUCTION

Arterial stiffness is an early marker of vascular damage and an independent predictor of major cardiovascular events. Pulse wave velocity (PWV) is currently the most widely used parameter for its assessment and is strongly supported by population-based studies. However, its measurement requires specialized equipment that may not be available in all clinical settings (1).

A potential alternative is morphological evaluation of the pulse waveform using volumetric analysis by lower-limb arterial plethysmography (AVP). Among these parameters the dicrotic notch (DN), corresponding to aortic valve closure, has been identified as a key feature. Loss of the DN has been observed in patients with arterial disease and vascular aging, suggesting a possible association with increased arterial stiffness (2,3).

Despite its physiological relevance, the relationship between DN loss and validated parameters such as PWV has not been clearly established. This study aimed to determine whether disappearance of the DN is associated with increased arterial stiffness assessed by PWV and whether it may be considered an alternative clinical marker in settings where other technological resources are unavailable (4).

METHODOLOGY

Study design and population

We conducted a descriptive, retrospective, observational study with analytical intent, based on registry data and manual data collection, designed to explore the association between arterial stiffness—assessed by PWV using the Arteriography® device—and loss of the DN at the thigh level, determined by lower-limb arterial plethysmography, in a cohort of patients evaluated between 2021 and 2022 at the Luis Felipe Gómez Isaza Vascular Laboratory in Medellín, Colombia. Interobserver agreement in identifying the DN was also analyzed using the kappa coefficient.

Individuals aged 18 years or older who had undergone both PWV measurement and lower-limb arterial plethysmography were included. Participants lacking either measurement were excluded.

Data processing

After approval from the institutional medical ethics committee, data were obtained from the Arteriography® device. Sociodemographic (age, sex, weight, height, and body mass index [BMI]) and hemodynamic variables (pulse wave velocity, systolic

blood pressure, diastolic blood pressure, heart rate, and central aortic pressure) were extracted. Subsequently, lower-limb arterial plethysmography studies performed with the SummitDoppler® device were reviewed to assess the presence of the DN at the thigh level and the ankle-brachial index (ABI).

The information was exported to Microsoft Office Excel® 2007, where variable recoding and data quality verification were performed. During data collection, periodic random reviews of entered information were conducted, allowing detection and timely correction of errors.

Statistical analysis

We conducted a descriptive analysis of the population. Quantitative variables were summarized using measures of central tendency (mean with standard deviation or median with interquartile range), depending on data distribution assessed by the Kolmogorov-Smirnov test.

Qualitative variables were described using absolute and relative frequencies.

Associations between 2 quantitative variables were evaluated using the Student *t* test or the Mann-Whitney *U* test, as appropriate. A *p* value < 0.05 was considered statistically significant.

A multivariable model using penalized logistic regression (ridge regression) was constructed to assess the association between absence of the DN and potential clinical confounders, including age, BMI, heart rate, and systolic blood pressure. This approach controlled for collinearity and avoided issues of perfect separation, ensuring stability of the estimates.

Intra- and interobserver agreement among experts was assessed using simple kappa or weighted quadratic kappa coefficients, as appropriate. Evaluators were blinded to PWV values when analyzing the dicrotic notch. In cases of disagreement, studies were jointly reviewed to reach consensus, which served as the reference standard.

Interpretation of agreement measures followed the Landis and Koch classification: < 0, no agreement; 0.00-0.40, poor; 0.41-0.60, moderate; 0.61-0.80, substantial; and 0.81-1.00, almost perfect agreement (5).

RESULTS

Data from 579 patients with recorded PWV measurements obtained using the Arteriography® device were reviewed; 160 met the inclusion criteria. A total of 419 patients were excluded because they lacked lower-limb arterial plethysmography records.

The mean age was 68.5 years (SD range, 54.9-82.1 years); 46.3% (*n* = 74) were men and 52.5% (*n* = 84) were women, with sex data missing in 1.2% (*n* = 2). Mean body weight was 68.7 kg (SD range, 54.5-82.9 kg), and the median BMI was 24.95 (IQR, 22.53-29.08). The mean ankle-brachial index was 0.98 (SD range, 0.61-1.36); 13.75% (*n* = 22) had ABI values > 1.4, indicative of peripheral arterial stiffness, while 33.75% (*n* = 56) had ABI values < 0.9, consistent with peripheral arterial disease.

Mean arterial pressure averaged 106 mm Hg, with a mean systolic blood pressure of 151.76 mm Hg and a mean central aortic pressure of 151.91 mm Hg. A total of 16.2% of patients had normal blood pressure, with mean systolic and diastolic pressures of 121 mm Hg and 70 mm Hg, respectively (Fig. 1).

The median PWV was 9.25 m/s (IQR, 7.9-10.6 m/s), with 36.25% (*n* = 58) of patients showing PWV values > 10 m/s; their mean age was 71.6 years (Table I; Figs. 2 and 3). No significant differences were observed between sexes: 30.95% of men and 42.86% of women had PWV > 10 m/s (*p* = 0.1735).

Interobserver agreement for identifying the DN in volume waveforms was moderate between observers 1 and 2 and substantial between observers 1 and 3 as well as between observers 2 and 3 (Table II).

A total of 37.5% (*n* = 60) of patients lacked a DN in the upper thigh volume waveform (Fig. 4).

Furthermore, PWV values were compared across groups with and without a DN at the thigh level. Patients with a preserved DN (*n* = 98) had a median PWV of 9.15 m/s (95% CI, 8.55-9.7), whereas those without a DN (*n* = 56) had a median PWV of 10.1 m/s (95% CI, 9.3-10.6). The absolute difference between groups was 0.95 m/s, which was statistically significant (*p* = 0.0025), with an effect size *r* = 0.244, indicating a small-to-moderate effect (Fig. 5).

A contingency table assessing the association between DN absence and arterial stiffness defined as PWV > 10 m/s showed that among 58 patients

with elevated PWV, 29 (50%) lacked a diastolic notch. This finding yielded a sensitivity of 50% and a speci-

ficity of 69.6% for detecting arterial stiffness, with an odds ratio of 2.29.

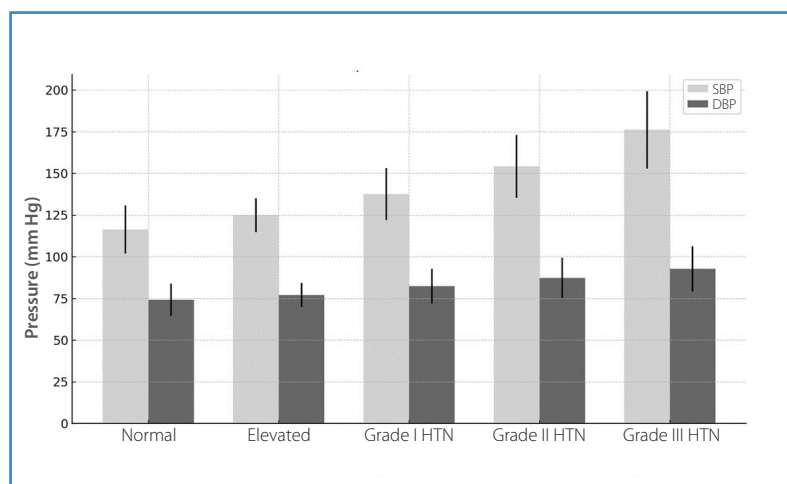


Figure 1. Distribution of blood pressure (error bars: ± 2 SD). SBP: systolic blood pressure; DBP: diastolic blood pressure; HTN: hypertension.

Table I. Classification of PWV by age

Age range	PWV (median and IQR)
30-40	9.25 (IQR, 7.60-10.90) m/s
40-50	8.30 (IQR, 7.40-8.90) m/s
50-60	9.15 (IQR, 6.80-9.90) m/s
60-70	9.70 (IQR, 8.05-10.73) m/s
> 70	9.80 (IQR, 8.53-10.78) m/s

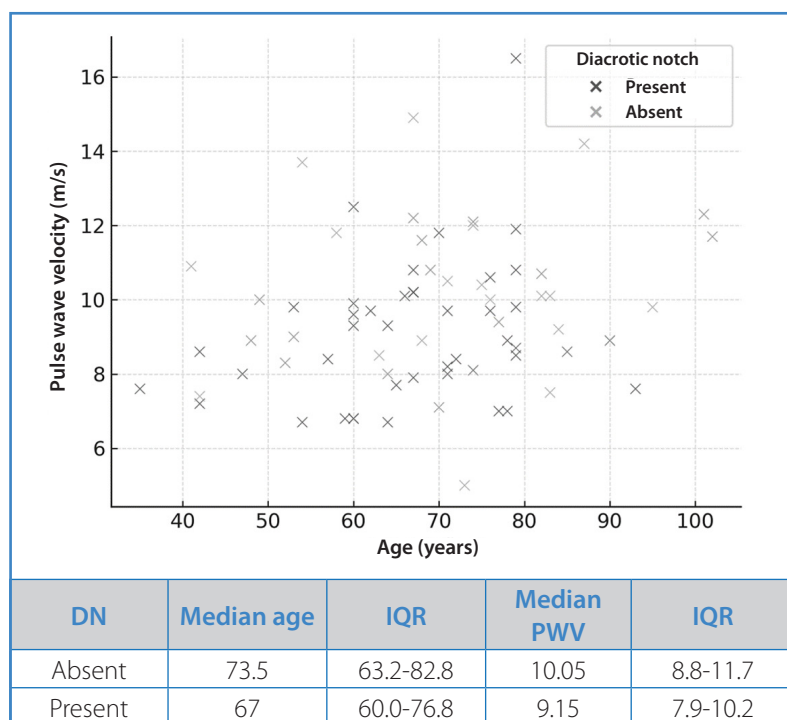


Figure 2. Relationship between age and PWV according to DN presence. DN: diastolic notch. PWV: pulse wave velocity.

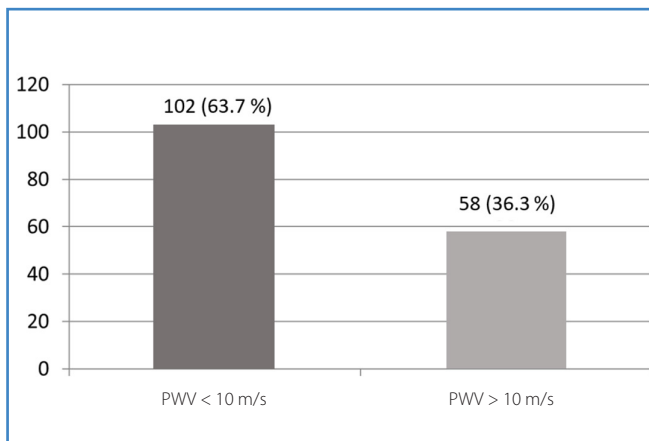


Figure 3. Distribution of patients according to PWV. PWV: pulse wave velocity.

Table II. Interobserver agreement for determination of the dicrotic notch

Comparison	Weighted kappa	95% CI	Interpretation	Significance
Observer 1 vs observer 2	0.510	0.291-0.729	Moderate agreement	$p = 0.017$
Observer 1 vs observer 3	0.694	0.492-0.896	Substantial agreement	$p = 0.002$
Observer 2 vs observer 3	0.802	0.627-0.977	Almost perfect agreement	$p < 0.001$

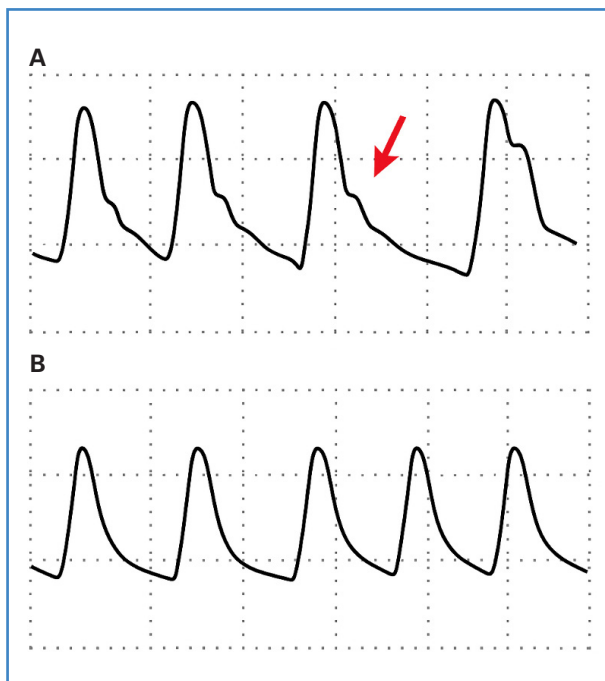


Figure 4. Presence of the DN in the upper thigh. A. Present. B. Absent. The red arrow indicates dicrotism. DN: dicrotic notch.

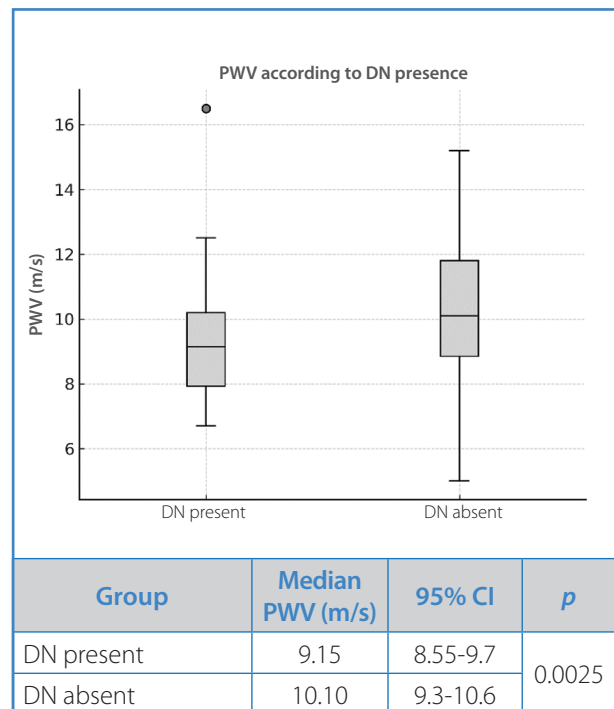


Figure 5. Comparison of PWV according to DN presence. DN: dicrotic notch; PWV: pulse wave velocity.

No clear association was found between PWV > 10 m/s and ABI > 1.4 ($p = 0.4665$) or between absence of the DN and ABI > 1.4 ($p = 0.7221$) (Fig. 6). Among patients with a pathological ABI (< 0.9), 54 cases were identified; 33 (61.1%) lacked a dicrotic notch, whereas 21 (38.9%) retained it.

In multivariable penalized logistic regression analysis, factors associated with absence of the DN were identified.

Older age was associated with increased odds of DN absence (adjusted OR, 1.23), as was higher heart rate (adjusted OR, 2.38). In contrast, higher BMI was associated with lower odds of DN absence (adjusted OR, 0.66). Systolic blood pressure showed a modest association (adjusted OR, 1.03).

These findings suggest that arterial stiffness, as reflected by loss of the dicrotic notch, is influenced by relevant hemodynamic and clinical factors. Full regression coefficients and odds ratios are presented in Table III.

DISCUSSION

In this study, a significant association was demonstrated between loss of the DN (DN) at the thigh level and increased PWV, a validated indicator of arterial stiffness. Patients without a DN showed a median PWV of 10.10 m/s (IQR, 8.85-11.80) compared with those in whom the DN was preserved, who had a median PWV of 9.15 m/s (IQR, 7.93-10.20), with a statistically significant difference ($p = 0.0025$). This finding supports the hypothesis that disappearance of the dicrotic notch, identified through volumetric analysis by arterial plethysmography (AVP), may constitute an indirect marker of increased arterial stiffness (6,7).

These results are consistent with pathophysiological principles explaining how increased arterial wall stiffness alters pressure wave dynamics, leading to earlier return of the reflected wave and reduced arterial distensibility. Clinically, this alteration may

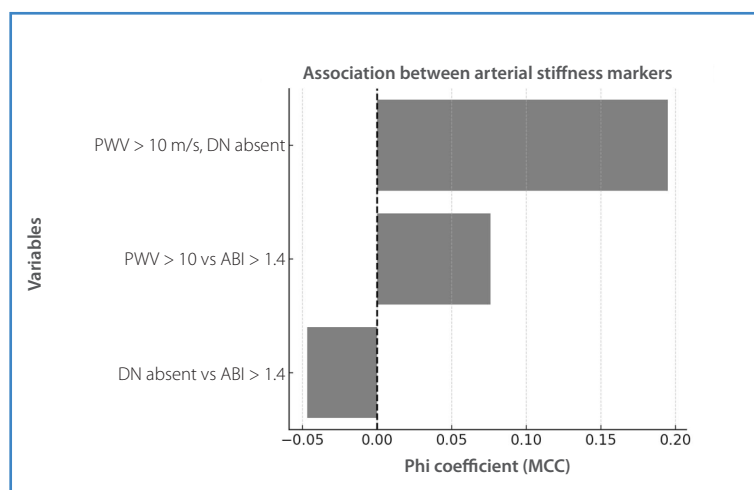


Figure 6. Comparison between arterial stiffness parameters.

Table III. Multivariate model results (penalized logistic regression)

Variable	Coefficient	Adjusted OR	95% CI
Age 2021	0.206	1.229	0.17-8.72
BMI	-0.414	0.661	0.09-4.69
HR	0.865	2.375	0.33-16.86
Systolic pressure	0.03	1.03	0.15-7.31

manifest as attenuation or disappearance of the dicrotic notch, as observed in the present study (6,7).

The fact that 37.5% of patients lacked a DN and that 36.25% had a PWV > 10 m/s—the threshold widely used to define significant arterial stiffness (8)—supports the potential value of morphological analysis of the volume waveform as a complementary diagnostic tool. Furthermore, the mean age of patients with PWV > 10 m/s was higher (71.6 years), which is consistent with the physiological progression of arterial stiffness with aging, as demonstrated in population-based studies (9-11). Of the 58 patients with elevated PWV, 29 (50%) showed absence of the dicrotic notch, yielding a specificity of 69.6% for detecting arterial stiffness and an odds ratio of 2.29, suggesting that the likelihood of arterial stiffness is more than twice as high in patients without a DN compared with those in whom it is preserved.

Interobserver agreement among evaluators ranged from moderate to almost perfect (weighted kappa, 0.510-0.802), providing methodological robustness to the visual assessment of the DN on plethysmographic recordings, an aspect that has not been widely explored in previous studies.

Another relevant aspect is the adequate representation of a population at cardiovascular risk, as only 16.2% of patients had blood pressure values within the normal range. Cardiovascular risk has been strongly associated with arterial stiffness (12,13). This is likely related to the fact that lower-limb arterial plethysmography is typically performed in patients with suspected peripheral arterial disease, a condition closely linked to cardiovascular risk factors (14). In this study, 33.75% of patients had an ankle-brachial index (ABI) < 0.9 , which is consistent with a diagnosis of peripheral arterial disease.

Regarding the comparison between systemic systolic blood pressure and central aortic pressure, it is noteworthy that under normal conditions central aortic pressure is expected to be significantly lower than peripheral systolic pressure due to pulse wave amplification. The finding that both pressures were nearly identical suggests a marked loss of arterial distensibility, likely due to advanced vascular stiffness, which is consistent with the high proportion of patients with increased arterial stiffness as assessed by PWV (36.25%) (15,16).

Although PWV measurement by tonometry or oscillometry is considered the reference standard, its availability in routine clinical settings is limited. In this context, identification of simple visual markers—such as the dicrotic notch—on plethysmography may offer an accessible and easily implementable alternative, particularly in populations at high cardiovascular risk. Notably, no association was found between ABI > 1.4 , traditionally interpreted as a marker of peripheral arterial stiffness, and parameters used to assess central arterial stiffness, such as PWV and DN presence. This finding is consistent with previous reports in which elevated ABI was not consistently associated with other stiffness measures. This suggests that ABI > 1.4 may reflect a distinct pathophysiological phenomenon, more closely related to medial arterial calcification (Mönckeberg sclerosis) than to the functional loss of elasticity characteristic of central arterial stiffness. This apparent dissociation between peripheral and central markers highlights the need for complementary tools in arterial stiffness assessment and underscores the need for further studies to clarify their true diagnostic and prognostic value in different clinical settings (17). Conversely, among patients with a pathological ABI (< 0.9), 33 individuals (61.1%) showed absence of the dicrotic notch, whereas 21 (38.9%) preserved it, supporting previous literature describing loss of waveform dicrotism as a reflection of peripheral arterial disease (18).

Several limitations should be acknowledged. Selection bias may be present, as the study population derived from a specific group (eg, patients with suspected arterial disease or referred for AVP). Information bias is also possible, since DN determination was visual and categorical, which introduces subjectivity. In addition, ABI measurements are technique-dependent, and measurement bias may exist due to technical differences among devices used for PWV or plethysmography, potentially affecting precision.

One of the main methodological challenges of this study was the visual assessment of the dicrotic notch, which, although performed by three independent observers with high agreement (kappa coefficient), remains subjective and dependent on evaluator expertise. The absence of an automated or semiquantitative method to quantify the presence

or depth of the DN represents an important limitation that may introduce classification bias.

Future studies should aim to develop digital analysis tools that allow objective assessment of this feature, for example by calculating the percentage depth of the notch relative to the baseline of the volumetric contour. Such an approach would standardize evaluation and facilitate clinical and research reproducibility.

Although the results support the assessment of the volume waveform as a marker of arterial stiffness, it is important to emphasize that this approach does not replace validated methods such as PWV. The dicrotic notch, evaluated by volumetric plethysmography, may provide an accessible qualitative approximation, but its clinical use should be interpreted with caution. Prospective studies with greater statistical power are required to evaluate its diagnostic and prognostic value, as well as its reproducibility and comparative utility against standard techniques in different clinical scenarios.

Further research is also needed to establish valid cutoff points and to explore reproducibility of this finding in other populations. It would be of future interest to assess whether loss of the DN could also serve as an independent predictor of clinically relevant outcomes, such as major cardiovascular events, thereby positioning AVP as a potential prognostic tool.

CONCLUSIONS

In this cohort, a significant association was identified between absence of the DN at the thigh level and elevated pulse wave velocity, suggesting that both markers may reflect increased arterial stiffness. These findings highlight the complementary utility of different diagnostic methods for arterial stiffness assessment and underscore the need for further studies controlling for clinical variables and potential confounders.

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