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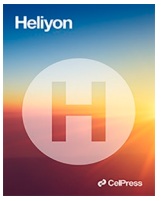

Research article

The association between pulse wave velocity and pregnancy-associated diseases: A systematic review and meta-analysis

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A R T I C L E I N F O

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A B S T R A C T

Background: Maintaining healthy vascular structure and function is important for a healthy pregnancy. Obesity is a well-known predictor for poor postoperative outcomes of vascular surgery. However, the association between pulse wave velocity (PWV), a well-recognized parameter for arterial stiffness assessment, and pregnancy-associated diseases is still unclear. Therefore, we conducted this systematic review, and a meta-analysis was performed to assess the relevant associations.

Methods: We systematically searched the Web of Science and PubMed databases to obtain articles on PWV and pregnancy-associated diseases published before April 2023. The mean with standard deviation was used to assess the differences in PWV in pregnant women with or without relevant diseases. Subgroup analysis was conducted according to specific types of PWV. The Newcastle–Ottawa Scale was used to evaluate the quality of the enrolled studies.

Results: A total of 6488 individuals from 21 studies were included. All enrolled studies were high-quality. Overall, the PWV was elevated in pregnant women who suffered from preeclampsia (mean difference (MD) = 0.67, 95 % confidence interval (CI): 0.51,0.83, $P < 0.00001$), hypertension (MD = 1.04, 95 % CI: 1.00,1.08, $P < 0.00001$), gestational diabetes mellitus (MD = 0.34, 95%CI: 0.19,0.48, $P < 0.00001$), and diabetes (MD = 0.49, 95%CI: 0.27,0.70, $P < 0.00001$). Subgroup analysis based on specific types of PWV showed similar results.

Conclusion: In our study, PWV is elevated in pregnancy-associated diseases, including preeclampsia, hypertension, and diabetes. The PWV assessment should be regarded as a clinical routine for pregnant women to prevent and manage cardiovascular diseases during pregnancy.

1. Introduction

With the younger onset of cardiometabolic disease and the delayed age of childbearing, the incidence of comorbidities and

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complications during pregnancy, such as pre-eclampsia and gestational diabetes, is increasing [1–5]. These complications can lead to low birth weight babies, increased maternal comorbidities, and even miscarriage and maternal death [6–9]. Maintaining healthy vascular structure and function is important for a healthy pregnancy. Arteriosclerosis is one of the manifestations of abnormal vascular status. Arteriosclerosis is associated with abnormal regulation of blood pressure, which in turn increases the risk of developing hyperemesis gravidarum and pre-eclampsia [10,11]. Arteriosclerosis is also affected by metabolic-related risk factors such as diabetes [12]. It is, therefore, necessary to analyze the link between arteriosclerosis and comorbidities and complications in pregnancy.

PWV, a non-invasive measure of arterial elasticity, represents an essential index for evaluating cardiovascular health and atherosclerosis burden in various populations [13,14]. Increased PWV values have been consistently associated with the development and progression of cardiovascular diseases, including arteriosclerosis, hypertension, and atrial fibrillation [15,16]. Nevertheless, the relationship between pre-eclampsia and PWV alterations remains unexplored, warranting further investigation to understand better the pathophysiological mechanisms involved.

PWV has been observed to be elevated to varying degrees during different gestational periods [17]. Several pregnancy-related comorbidities, including hypertension with pregnancy, gestational diabetes mellitus, and gestational hypertension, increase the risk of adverse pregnancy outcomes such as pre-eclampsia. The development of these conditions is characterized by alterations in placental blood flow resistance, abnormal endothelial cell function, and changes in blood composition, which in turn may impact vascular elasticity. However, there remains a need to clarify the specific circumstances in which pregnant women exhibit elevated PWV compared to healthy pregnant women and understand the relationship between elevated PWV and pregnancy-associated diseases. Accordingly, this study aims to investigate the association between PWV and pregnancy-associated diseases to characterize this relationship further.

2. Materials and methods

This work was executed by the Preferred Reporting Items for Systemic Reviews and Meta-analysis(PRISMA) guidelines [18]. The protocol for this systematic review was developed prospectively and registered in PROSPERO (CRD42023438243).

2.1. Literature search

We conducted a systematic literature search by searching PubMed and Web of Science in April 2023. Studies that assessed the association between PWV and pregnancy were identified through a full-text review. The following terms and their combinations were employed: “PWV,” “pulse wave velocity,” “pregnancy,” “gestational,” “preeclampsia,” “gestational diabetes mellitus,” “GDM,” “gestational hypertension,” “hypertension with pregnancy.”

2.2. Selection criteria

The inclusion criteria were as follows [1]: studies that assessed the association between PWV and pregnancy-associated disease, including preeclampsia, gestational diabetes, gestational hypertension, and chronic hypertension with pregnancy-associated disease [2]; the results contained mean with the standard deviation or median with quartile of any types of PWV in pregnant women with or without diseases mentioned above.

The exclusion criteria were as follows [1]: studies that were reviews, letters, meeting abstracts, case reports, commentary, or editorials [2]; duplicate studies with overlapping data [3]; studies that reported invalid data that could not be pooled; and [4] the control population was non-pregnant women.

According to the selection criteria, the initial studies screening was based on titles and abstracts. Then, the full texts of the potential studies were assessed. An additional manual search of references from identified studies was also performed. All studies were independently screened by two reviewers (Jie Xu and Yucong Zhang). A third researcher (Yue Huang) was consulted to resolve disagreements.

2.3. Data extraction and quality assessment

Data extraction was conducted by two independent reviewers. Sample size, age, BMI, types of PWV, and types of pregnancy-associated disease were collected as baseline data.

To assess the association between PWV and pregnancy-associated disease, we extracted the results of the PWV assessment.

Two reviewers independently assessed the quality of enrolled studies by using the Newcastle–Ottawa Quality Assessment Scale (NOS)(56). A third reviewer was discussed to resolve discrepancies. Funnel plots were applied to examine the potential publication bias for comparisons that included more than 5 studies.

2.4. Data analysis

Medians with quartiles were transformed into means with standard deviations for pooled estimates by using the webpage tool in the BOX-COX manner developed by McGrath et al. [19]. RevMan 5.3 (the Nordic Cochrane Centre, Copenhagen, Denmark) was used to conduct the meta-analysis. A random-effects model was applied for pooled analysis to achieve conservative results. Heterogeneity was tested by the chi-squared test and I^2 statistic. $p < 0.05$ or $I^2 > 50$ % indicated significant heterogeneity. The overall effects were

determined by the Z test, and $p < 0.05$ was considered statistically significant. Subgroup analysis was performed based on specific adverse events. Subgroup analysis was conducted according to specific types of PWV.

3. Results

After removing duplicate articles, 443 articles were identified in the initial database search. After screening titles and abstracts, 47 articles remained for further full-text evaluation. Finally, 21 articles were included in the meta-analysis [20–40] (see Fig. 1). Supplementary Table 1 summarizes the basic information and patient baseline characteristics of these studies. Supplementary Table 2 summarizes the quality assessment of articles included by the Newcastle-Ottawa Scale.

3.1. Differences in PWV in pregnant women with or without preeclampsia

Ten cross-sectional studies assessed PWV at the time of preeclampsia [20–28,38]. The pooled results showed that the PWV (mean difference (MD) = 0.67, 95 % confidence interval (CI): 0.51,0.83, $P < 0.00001$) was significantly higher in women with preeclampsia than those without preeclampsia. However, Nienke et al. [27] did not find a significant association between cfPWV and preeclampsia development (see Fig. 2). In the subgroup analyses, both cfPWV and apPWV increased significantly, similar to the overall results. Publication bias was assessed by a funnel plot (Supplementary Fig. 1), which indicated moderate publication bias.

3.2. Differences in PWV in pregnancies with or without hypertension

Three studies reported the PWV in pregnancies with hypertension [21,37,40]. The PWV (MD = 1.04, 95 % CI: 1.00,1.08, $P < 0.00001$) was elevated in pregnancies with hypertension, including hcPWV and APWV (see Fig. 3).

3.3. Differences in PWV in pregnancies with or without gestational diabetes mellitus (GDM)

Seven studies reported PWV in pregnancies with GDM(29,30,30,33–35,39). The pooled results showed that PWV (MD = 0.34, 95%

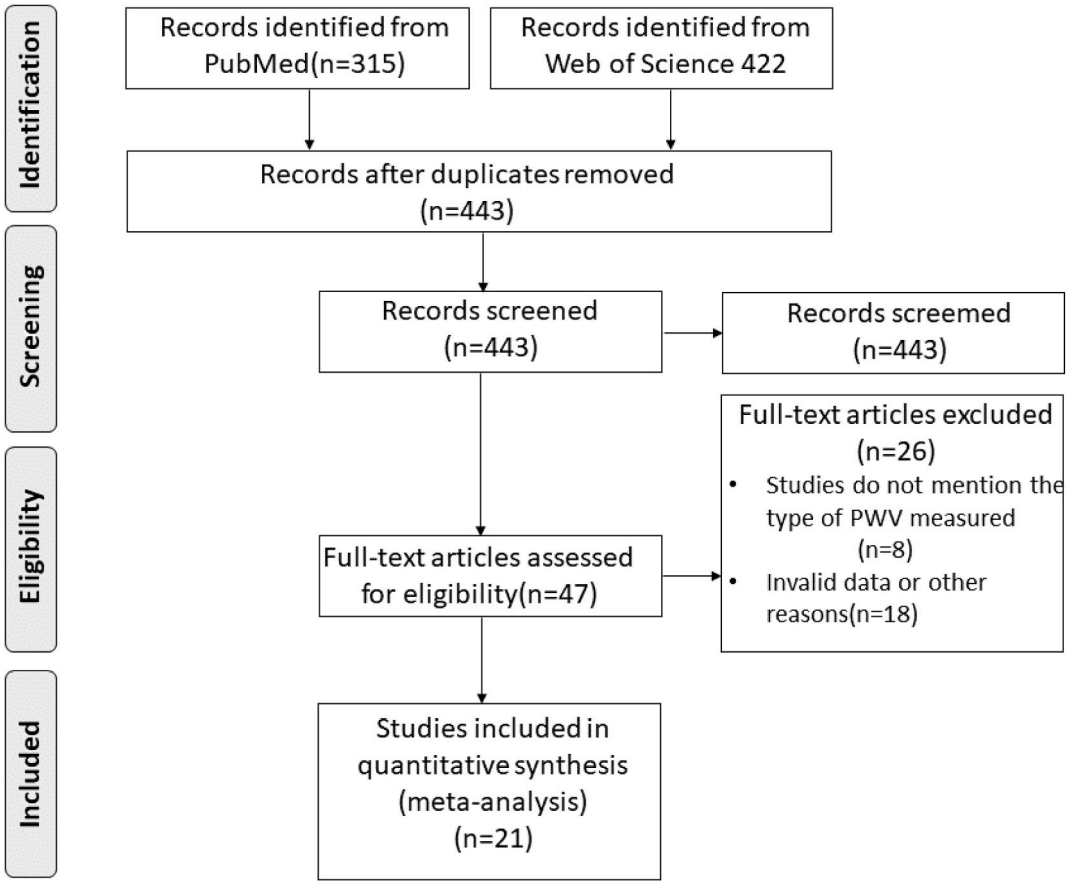

Fig. 1. Preferred reporting items for systemic reviews and meta-analysis flow diagram of literature screening.

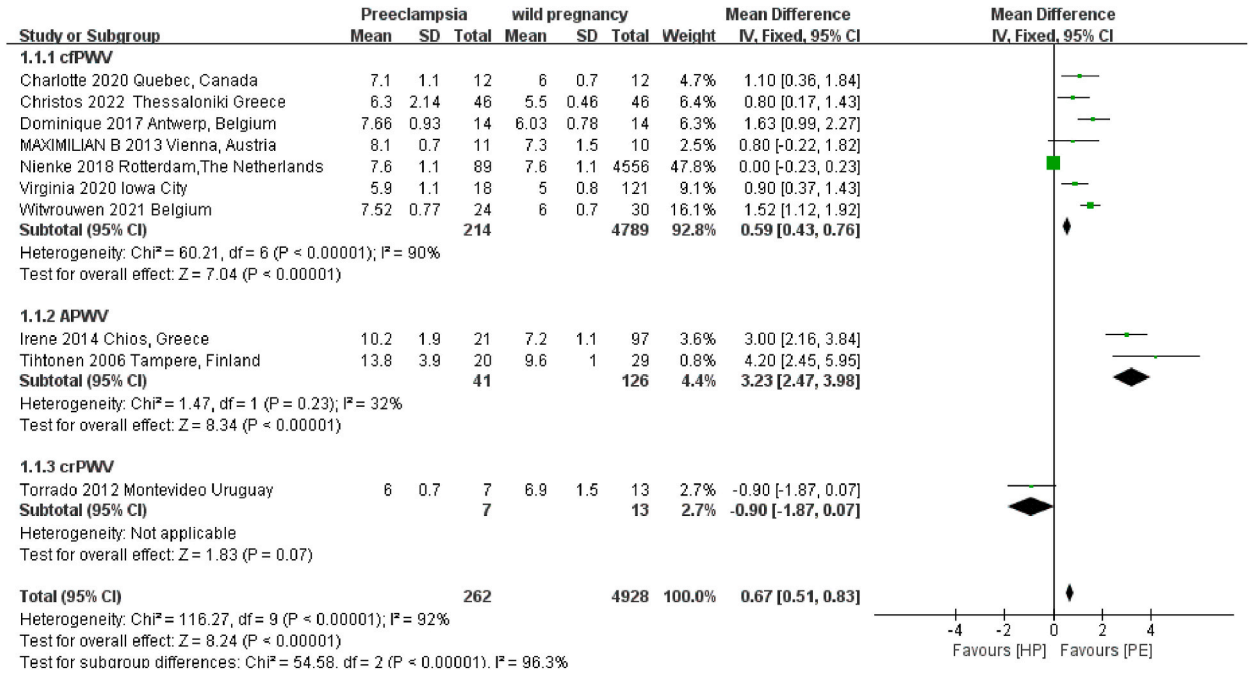

Fig. 2. Forest plot of PWV in women with or without preeclampsia. PWV, pulse wave velocity.

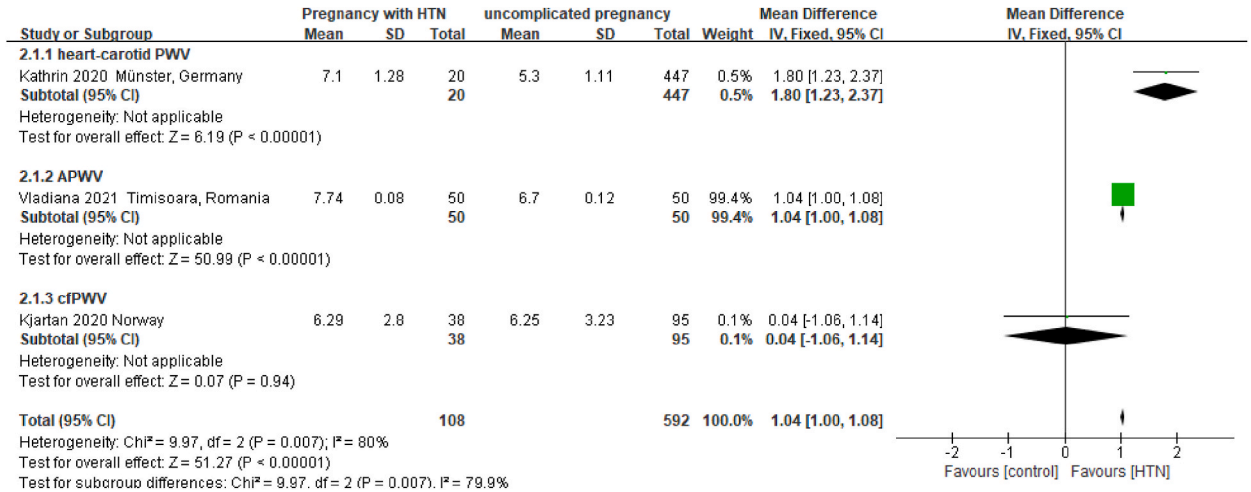

Fig. 3. Forest plot of PWV in pregnancies with or Without hypertension. PWV, pulse wave velocity; HTN, hypertension.

CI: 0.19,0.48, P < 0.00001) was significantly increased in pregnant women with GDM than those without, including cfPWV and carotid-finger PWV, but not apPWV. However, two studies did not show a significant association between aortic PWV and the incidence of GDM (see Fig. 4). Publication bias was assessed by a funnel plot (Fig. S2), which indicated moderate publication bias.

3.4. Differences in PWV in pregnancies with or without diabetes

The pooled results showed that PWV (MD = 0.49, 95%CI: 0.27,0.70, P < 0.00001) was significantly higher in pregnant women with diabetes than those without diabetes, including cfPWV and hcPWV. The heterogeneity was significant (p = 0.007) among the included studies (see Fig. 5).

4. Discussion

PWV is the gold standard for assessing the degree of arteriosclerosis and evaluating the risk of cardiovascular disease (CVD)

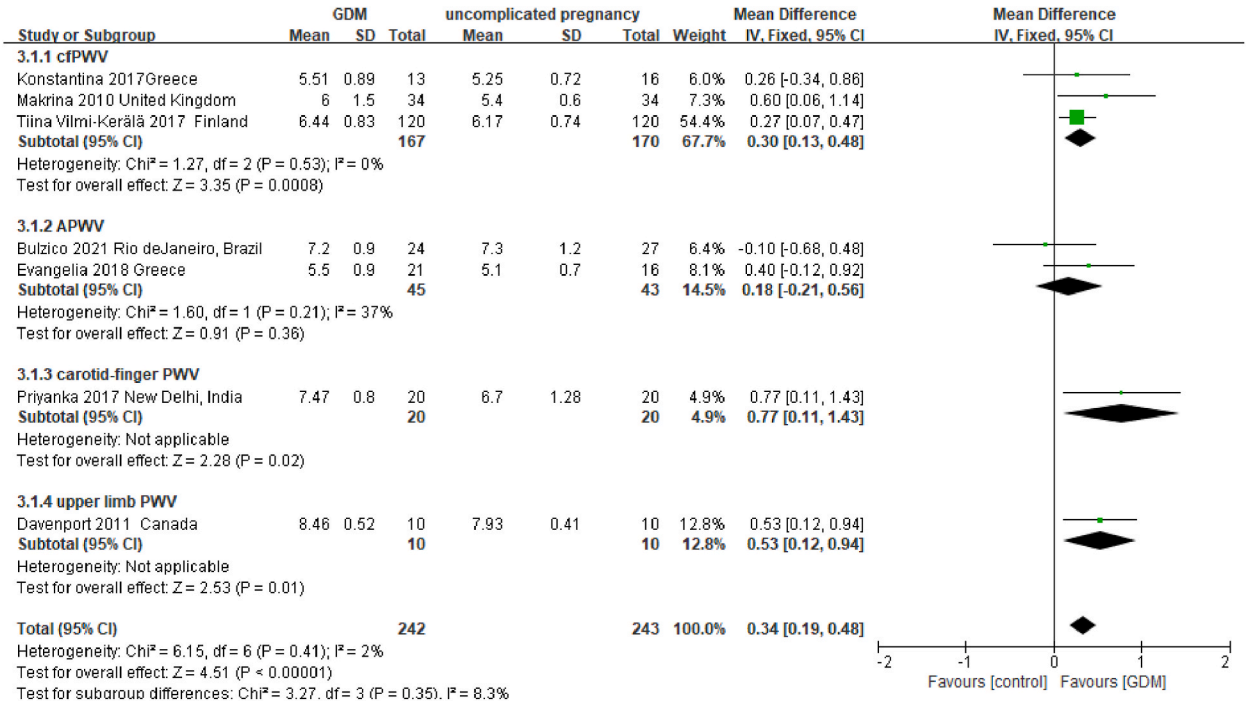

Fig. 4. Forest plot of PWV in Pregnancies with or Without GDM. PWV, pulse wave velocity; GDM, gestational diabetes mellitus.

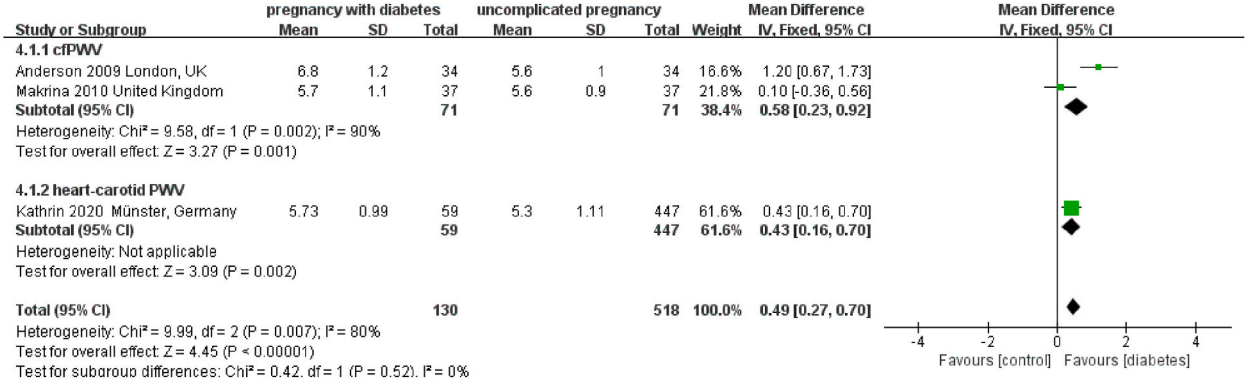

Fig. 5. Forest plot of PWV in Pregnancies with or without Diabetes. PWV, pulse wave velocity.

occurrence. Our findings demonstrated that pregnant women with a history of pre-eclampsia exhibited elevated PWV, as do those with other pregnancy complications, which were consistent with previous studies evaluating endothelial function. These studies have reported decreased flow-mediated dilation in the brachial or radial arteries of women with pre-eclampsia, indicating endothelial dysfunction [41–43]. However, the causal relationship between changes in PWV and the development of pre-eclampsia remains unclear.

Preeclampsia is a multisystem disorder specific to pregnancy, characterized by hypertension and proteinuria [44]. It is considered one of the most prevalent pregnancy complications worldwide, contributing to maternal morbidity and mortality rates and preterm neonatal delivery [45,46]. Furthermore, accumulating evidence has highlighted a significant association between pre-eclampsia and increased long-term risks of cardiovascular disease. The pathophysiology underlying pre-eclampsia remains incompletely understood. However, current research suggests that an intricate interplay between dysregulation of the renin-angiotensin-aldosterone system, endothelial dysfunction, and alterations in hemostasis and blood composition contributes to disease development. Notably, placental abnormalities, including inadequate trophoblast invasion and the formation of a shallow, defective spiral artery, lead to impaired uteroplacental blood flow, oxidative stress, and systemic inflammation.

Gestation with hypertension was also associated with a significant elevation in PWV compared to normal pregnancies, as reported by prior research. This elevation may be attributed to arterial remodeling and thickening resulting from vascular injury and the

inflammatory response of hypertension [47]. Furthermore, hypertension during pregnancy often leads to alterations in various pathophysiological parameters, such as increased blood volume, cardiac output, and peripheral vascular resistance, which may contribute to elevated PWV. These changes further increase the risk of cardiovascular disease and adversely affect maternal and fetal health.

Our meta-analysis found that gestational diabetes mellitus (GDM) similarly elevated PWV in pregnant women. To the best of our knowledge, this is the first meta-analysis reporting the effect of GDM on arterial stiffness during pregnancy. The elevation in PWV was more pronounced in peripheral arteries compared to the aorta, potentially due to a slower peripheral vascular blood flow leading to a more pronounced persistent hyperglycemic state. This hyperglycemic state induces an inflammatory response and impairs endothelial function, ultimately resulting in vascular sclerosis [48–50]. Additionally, it has been established that women with GDM have a significantly higher risk of developing pre-eclampsia, which may explain why GDM is associated with adverse pregnancy outcomes. The role of PWV in the development of pre-eclampsia in patients with gestational diabetes should be investigated in the future.

Furthermore, pregnant women with pre-existing diabetes mellitus also exhibited elevated PWV compared to normal pregnancies, although the magnitude of this change was less pronounced than in women with GDM. This difference may be attributed to the altered hormone levels and blood flow in pregnant women with diabetes mellitus. Although insufficient evidence currently supports an increased risk of pre-eclampsia in women with diabetes mellitus during pregnancy, the presence of common factors contributing to vascular stiffness in such patients cannot be ignored.

The current studies regarding PWV and pregnancy were cross-sectional studies; cohort studies should be conducted to provide longitudinal evidence further to confirm the association between complicated pregnancy and PWV. In addition, future studies should identify appropriate kinds of PWV for predicting the risk of cardiovascular diseases. The PWV change before pregnancy, during pregnancy, and after delivery should be analyzed, especially for different stages of conception. The PWV examination should be regarded as a clinical routine before pregnancy, which may be beneficial for preventing and managing cardiovascular diseases during pregnancy. Moreover, it is of great significance to investigate the role of pregnancy in the development of cardiovascular diseases for arteriosclerosis women, which requires much longer follow-up and comparison with women without a history of pregnancy. In-time and effective management strategy should be established for pregnant women with arteriosclerosis to prevent further cardiovascular diseases.

5. Limitation

Some limitations of the current study should be noted. All included studies were cross-sectional evidence, which could not confirm the causal relationship between elevated PWV and complications in pregnancy. Second, the types of PWV varied among the included studies, although we conducted relevant subgroup analysis.

6. Conclusion

In our study, PWV is elevated in pregnancy-associated diseases, including preeclampsia, hypertension, and diabetes. The PWV assessment should be regarded as a clinical routine for pregnant women to prevent and managing cardiovascular diseases during pregnancy.

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CRediT authorship contribution statement

Jie Xu: Writing – original draft, Formal Analysis, Investigation. **Yucong Zhang:** Writing – original draft, Formal Analysis, Investigation. **Yue Huang:** Formal Analysis, Investigation, Validation. **Hao Nie:** Formal Analysis, Investigation, Visualization. **Jinhua Yan:** Writing – review & editing. **Lei Ruan:** Supervision, Project administration. **Cuntai Zhang:** Conceptualization, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e29281.

References

[1] K.P. Ramlakhan, M.R. Johnson, J.W. Roos-Hesselink, Pregnancy and cardiovascular disease, Nat. Rev. Cardiol. 17 (11) (2020 Nov) 718–731.
[2] F.A. English, L.C. Kenny, F.P. McCarthy, Risk factors and effective management of preeclampsia, Integrated Blood Pres. Control 8 (2015) 7–12.
[3] L.C. Chappell, S. Enye, P. Seed, A.L. Briley, L. Poston, A.H. Shennan, Adverse perinatal outcomes and risk factors for preeclampsia in women with chronic hypertension, Hypertension 51 (4) (2008 Apr) 1002–1009.
[4] J.G. Ray, M.J. Vermeulen, M.J. Schull, D.A. Redelmeier, Cardiovascular health after maternal placental syndromes (CHAMPS): population-based retrospective cohort study, Lancet 366 (9499) (2005 Nov 19) 1797–1803.
[5] U. Kampmann, L.R. Madsen, G.O. Skajaa, D.S. Iversen, N. Moeller, P. Ovesen, Gestational diabetes: a clinical update, World J. Diabetes 6 (8) (2015 Jul 25) 1065–1072.
[6] A. Bokslag, M. van Weissenbruch, B.W. Mol, C.J.M. de Groot, Preeclampsia; short and long-term consequences for mother and neonate, Early Hum. Dev. 102 (2016 Nov 1) 47–50.
[7] S.M. Goffin, J.G.B. Derraik, K.M. Groom, W.S. Cutfield, Maternal pre-eclampsia and long-term offspring health: is there a shadow cast? Pregnancy Hypertens 12 (2018 Apr 1) 11–15.
[8] E.P. Gunderson, V. Chiang, M.J. Pletcher, D.R. Jacobs, C.P. Quesenberry, S. Sidney, et al., History of gestational diabetes mellitus and future risk of atherosclerosis in mid-life: the Coronary Artery Risk Development in Young Adults study, J. Am. Heart Assoc. 3 (2) (2014 Mar 12) e000490.
[9] S.E. Maynard, R. Thadhani, Pregnancy and the kidney, J. Am. Soc. Nephrol. 20 (1) (2009 Jan) 14.
[10] A.L. Tranquilli, G. Dekker, L. Magee, J. Roberts, B.M. Sibai, W. Steyn, et al., The classification, diagnosis and management of the hypertensive disorders of pregnancy: a revised statement from the ISSHP, Pregnancy Hypertens Int J Womens Cardiovasc Health 4 (2) (2014 Apr 1) 97–104.
[11] F. Wu, F.J. Tian, Y. Lin, Oxidative stress in placenta: health and diseases, BioMed Res. Int. 2015 (2015) 293271.
[12] A. Poznyak, A.V. Grechko, P. Poggio, V.A. Myasoedova, V. Alfieri, A.N. Orekhov, The diabetes mellitus-atherosclerosis connection: the role of lipid and glucose metabolism and chronic inflammation, Int. J. Mol. Sci. 21 (5) (2020 Mar 6) 1835.
[13] C. Vlachopoulos, K. Aznaouridis, C. Stefanadis, Prediction of cardiovascular events and all-cause mortality with arterial stiffness: a systematic review and meta-analysis, J. Am. Coll. Cardiol. 55 (13) (2010 Mar 30) 1318–1327.
[14] I. Sequí-Domínguez, I. Cavero-Redondo, C. Álvarez-Bueno, D.P. Pozuelo-Carrascosa, S. Nuñez de Arenas-Arroyo, V. Martínez-Vizcaíno, Accuracy of pulse wave velocity predicting cardiovascular and all-cause mortality. A systematic review and meta-analysis, J. Clin. Med. 9 (7) (2020 Jul 2) 2080.
[15] S. Lopes, V. Afreixo, M. Teixeira, C. Garcia, C. Leitão, M. Gouveia, et al., Exercise training reduces arterial stiffness in adults with hypertension: a systematic review and meta-analysis, J. Hypertens. 39 (2) (2021 Feb 1) 214–222.
[16] L.Y. Chen, M.J.G. Leening, F.L. Norby, N.S. Roetker, A. Hofman, O.H. Franco, et al., Carotid intima-media thickness and arterial stiffness and the risk of atrial fibrillation: the atherosclerosis risk in communities (ARIC) study, multi-ethnic study of atherosclerosis (MESA), and the rotterdam study, J. Am. Heart Assoc. 5 (5) (2016 May 20) e002907.
[17] V. Turi, S. Dragan, M. Iurciuc, L. Moleriu, S. Bungau, D.M. Tit, et al., Arterial function in healthy pregnant women vs. Non-pregnant women-A 10-year study, Diagn Basel Switz 10 (6) (2020 Jun 5) 374.
[18] A. Liberati, D.G. Altman, J. Tetzlaff, C. Mulrow, P.C. Gøtzsche, J.P.A. Ioannidis, et al., The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration, BMJ 339 (2009 Jul 21) b2700.
[19] S. McGrath, X. Zhao, R. Steele, B.D. Thombs, A. Benedetti, DEPRESsion Screening Data (DEPRESSD) Collaboration. Estimating the sample mean and standard deviation from commonly reported quantiles in meta-analysis, Stat. Methods Med. Res. 29 (9) (2020 Sep) 2520–2537.
[20] C.W. Usselman, T.E. Adler, Y. Coovadia, C. Leone, M.J. Paidas, N.S. Stachenfeld, A recent history of preeclampsia is associated with elevated central pulse wave velocity and muscle sympathetic outflow, Am. J. Physiol. Heart Circ. Physiol. 318 (3) (2020 Mar 1) H581–H589.
[21] V. Turi, S. Iurciuc, O.M. Creţu, D.M. Tit, S. Bungau, A. Apostol, et al., Arterial function in hypertensive pregnant women. Is arterial stiffness a marker for the outcomes in pregnancy? Life Sci. 264 (2021 Jan 1) 118723.
[22] K.M.H. Tihtonen, T. Kööbi, J.T. Uotila, Arterial stiffness in preeclamptic and chronic hypertensive pregnancies, Eur. J. Obstet. Gynecol. Reprod. Biol. 128 (1–2) (2006) 180–186.
[23] M.B. Franz, M. Burgmann, A. Neubauer, H. Zeisler, R. Sanani, M. Gottsauner-Wolf, et al., Augmentation index and pulse wave velocity in normotensive and pre-eclamptic pregnancies, Acta Obstet. Gynecol. Scand. 92 (8) (2013 Aug) 960–966.
[24] C. Anthoulakis, A. Mamopoulos, Augmentation index and pulse wave velocity in normotensive versus preeclamptic pregnancies: a prospective case–control study using a new oscillometric method, Ann. Med. 54 (1) (2022 Dec 31) 1–10.
[25] V.R. Nuckols, S.W. Holwerda, R.E. Luehrs, L.E. DuBose, A.K. Stroud, D. Brandt, et al., Beat-to-Beat blood pressure variability in the first trimester is associated with the development of preeclampsia in a prospective cohort: relation with aortic stiffness, Hypertens Dallas Tex 1979 76 (6) (2020 Dec) 1800–1807.
[26] D. Mannaerts, E. Faes, I. Goovaerts, T. Stoop, J. Cornette, W. Gyselaers, et al., Flow-mediated dilation and peripheral arterial tonometry are disturbed in preeclampsia and reflect different aspects of endothelial function, Am. J. Physiol. Regul. Integr. Comp. Physiol. 313 (5) (2017 Nov 1) R518–R525.
[27] N.E. Bergen, S. Schalekamp-Timmermans, J. Roos-Hesselink, J.E. Roeters van Lennep, V.V.W. Jaddoe, E.A.P. Steegers, Hypertensive disorders of pregnancy and subsequent maternal cardiovascular health, Eur. J. Epidemiol. 33 (8) (2018 Aug) 763–771.
[28] I. Witvrouwen, D. Mannaerts, J. Ratajczak, E. Boeren, E. Faes, A.H. Van Craenenbroeck, et al., MicroRNAs targeting VEGF are related to vascular dysfunction in preeclampsia, Biosci. Rep. 41 (8) (2021 Aug 27) BSR20210874.
[29] D.A. Bulzico, L. Zajdenverg, C.A. Cabizuca, J.E.P. de Oliveira, G.F. Salles, Assessment of arterial stiffness in women with gestational diabetes, Diabet Med J Br Diabet Assoc 29 (2) (2012 Feb) 227–231.
[30] E. Kintiraki, K. Dipla, A. Triantafyllou, N. Koletsos, I. Grigoriadou, P. Poulakos, et al., Blunted cerebral oxygenation during exercise in women with gestational diabetes mellitus: associations with macrovascular function and cardiovascular risk factors, Metabolism 83 (2018 Jun) 25–30.
[31] K. Dipla, A. Triantafyllou, I. Grigoriadou, E. Kintiraki, G.A. Triantafyllou, P. Poulios, et al., Impairments in microvascular function and skeletal muscle oxygenation in women with gestational diabetes mellitus: links to cardiovascular disease risk factors, Diabetologia 60 (1) (2017 Jan) 192–201.
[32] J.M. Anderson, M.D. Savvidou, C. Kaihura, C.M. McEniery, K.H. Nicolaides, Maternal arterial stiffness in pregnancies affected by Type 1 diabetes mellitus, Diabet Med J Br Diabet Assoc 26 (11) (2009 Nov) 1135–1140.
[33] M.D. Savvidou, J.M. Anderson, C. Kaihura, K.H. Nicolaides, Maternal arterial stiffness in pregnancies complicated by gestational and type 2 diabetes mellitus, Am. J. Obstet. Gynecol. 203 (3) (2010 Sep) 274.e1–274.e7.
[34] T. Vilmi-Kerälä, A. Lauhio, T. Tervahartiala, O. Palomäki, J. Uotila, T. Sorsa, et al., Subclinical inflammation associated with prolonged TIMP-1 upregulation and arterial stiffness after gestational diabetes mellitus: a hospital-based cohort study, Cardiovasc. Diabetol. 16 (1) (2017 Apr 13) 49.
[35] P. Garg, S. Badhwar, A.K. Jaryal, G. Kachhawa, K.K. Deepak, A. Kriplani, The temporal trend of vascular function in women with gestational diabetes, Vasc Med Lond Engl 22 (2) (2017 Apr) 96–102.
[36] I. Katsipi, K. Stylianou, I. Petrakis, A. Passam, E. Vardaki, F. Parthenakis, et al., The use of pulse wave velocity in predicting pre-eclampsia in high-risk women, Hypertens. Res. 37 (8) (2014 Aug) 733–740.

[37] K.O. de Murcia, U. Möllmann, C. Opitz, H.A. Köster, M. Möllers, K. Hammer, et al., Wave intensity analysis of maternal arterial stiffness: augmentation index and pulse wave velocity in pregnancies complicated by diabetes or hypertension, Arch. Gynecol. Obstet. 301 (5) (2020 May) 1199–1205.
[38] J. Torrado, I. Farro, F. Farro, D. Bia, Y. Zócalo, C. Sosa, et al., Carotid-radial pulse wave velocity as an alternative tool for the evaluation of endothelial function during pregnancy: potential role in identifying hypertensive disorders of pregnancy, Annu Int Conf IEEE Eng Med Biol Soc IEEE Eng Med Biol Soc Annu Int Conf 2012 (2012) 5603–5606.
[39] M.H. Davenport, R. Goswami, J.K. Shoemaker, M.F. Mottola, Influence of hyperglycemia during and after pregnancy on postpartum vascular function, Am. J. Physiol. Regul. Integr. Comp. Physiol. 302 (6) (2012 Mar 15) R768–R775.
[40] K. Moe, M. Sugulle, R. Dechend, K. Angel, A.C. Staff, Functional and structural vascular biomarkers in women 1 year after a hypertensive disorder of pregnancy, Pregnancy Hypertens 21 (2020 Jul) 23–29.
[41] O.P. Oliveira, E. Araujo Júnior, J.W. Lima, E.M. Salustiano, R. Ruano, W.P. Martins, et al., Flow-mediated dilation of brachial artery and endothelial dysfunction in pregnant women with preeclampsia: a case control study, Minerva Ginecol. 67 (4) (2015 Aug) 307–313.
[42] T. Saitou, K. Watanabe, H. Kinoshita, A. Iwasaki, Y. Owaki, H. Matsushita, et al., Hypoalbuminemia is related to endothelial dysfunction resulting from oxidative stress in parturients with preeclampsia, Nagoya J. Med. Sci. 83 (4) (2021 Nov) 741–748.
[43] M.K. Sandvik, E. Leirgul, O. Nygård, P.M. Ueland, A. Berg, E. Svarstad, et al., Preeclampsia in healthy women and endothelial dysfunction 10 years later, Am. J. Obstet. Gynecol. 209 (6) (2013 Dec) 569.e1–569.e10.
[44] Hypertension in pregnancy, Report of the American college of obstetricians and gynecologists' task force on hypertension in pregnancy, Obstet. Gynecol. 122 (5) (2013 Nov) 1122–1131.
[45] M.D. Lindheimer, S.J. Taler, F.G. Cunningham, Hypertension in pregnancy, J Am Soc Hypertens JASH 4 (2) (2010) 68–78.
[46] U. Högberg, The World Health Report 2005: "make every mother and child count" - including Africans, Scand. J. Publ. Health 33 (6) (2005) 409–411.
[47] H. Qu, R.A. Khalil, Vascular mechanisms and molecular targets in hypertensive pregnancy and preeclampsia, Am. J. Physiol. Heart Circ. Physiol. 319 (3) (2020 Sep 1) H661–H681.
[48] P. Valero, G. Fuentes, M. Cornejo, S. Vega, A. Grismaldo, F. Pardo, et al., Exposome and foetoplacental vascular dysfunction in gestational diabetes mellitus, Mol. Aspect. Med. 87 (2022 Oct) 101019.
[49] M.M. Roca-Rodríguez, C. López-Tinoco, M. Murri, A. Fernández-Deudero, M.V. García-Palacios, M.A. García-Valero, et al., Postpartum development of endothelial dysfunction and oxidative stress markers in women with previous gestational diabetes mellitus, J. Endocrinol. Invest. 37 (6) (2014 Jun) 503–509.
[50] T. Sáez, P. de Vos, L. Sobrevia, M.M. Faas, Is there a role for exosomes in foetoplacental endothelial dysfunction in gestational diabetes mellitus? Placenta 61 (2018 Jan) 48–54.