Section: Miscellaneous

Original Research Article

PREOPERATIVE ECHOCARDIOGRAPHIC AND ULTRASOUND PREDICTORS OF HYPOTENSION AFTER NEURAXIAL ANAESTHESIA: A SYSTEMATIC REVIEW OF LVEF, GLOBAL LONGITUDINAL STRAIN, DIASTOLIC FUNCTION AND INFERIOR VENA CAVA INDICES

Mohit Kumar[1], Neha Kathor[2], Manoj Kumar[3], Bhawna Saini [4] , Daya Krishna [5]

[1]Assistant Professor, Department of Anaesthesiology, Veer Chandra Singh Garhwali Government Institute of Medical Science & Research Srinagar, Uttarakhand, India.
[2]Associate Professor, Department of Anaesthesiology, Shri Guru Ram Rai Institute of Medical & Health Sciences Shri Mahant Indiresh Hospital Dehradun, Uttarakhand, India.
[3]Assistant Professor, Department of General Medicine, Mahatma Vidur Autonomous State Medical College, Bijnor, Uttar Pradesh, India.
[4]Assistant Professor, Department of Pharmacology, Himalayan Institute of Medical Sciences Swami Rama Himalayan University Jolly Grant, Dehradun, Uttarakhand, India
[5]Professor, Department of Orthopedics, Veer Chandra Singh Garhwali Government Institute of Medical Science & Research Srinagar, Uttarakhand, India.

Received : *10/05/2026*
Received in revised form : *28/07/2026*
Accepted : *14/07/2026*

Corresponding Author:
Dr. Neha Kathor,
Associate Professor, Department of Anaesthesiology, Shri Guru Ram Rai Institute of Medical & Health Sciences Shri Mahant Indiresh Hospital Dehradun, Uttarakhand, India.
Email: nkathor@gmail.com

DOI: 10.70034/ijmedph.2026.3.162

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (3); 1004-1010

ABSTRACT

Background: Hypotension after neuraxial anaesthesia remains a common and clinically important perioperative event, particularly in older, obstetric and cardiovascularly vulnerable patients. Conventional clinical assessment and left ventricular ejection fraction (LVEF) may not fully capture preload status, diastolic reserve or subclinical myocardial dysfunction. Global longitudinal strain (GLS) is theoretically attractive because it can detect early myocardial impairment, but its direct role in predicting post-neuraxial hypotension is uncertain. **Objective:** To synthesize available evidence on preoperative echocardiographic and ultrasound-derived predictors of hypotension after spinal or epidural anaesthesia, with emphasis on LVEF, GLS, diastolic indices and inferior vena cava (IVC) parameters.

Materials and Methods: A PRISMA 2020-oriented systematic literature review was conducted across PubMed/MEDLINE, Scopus, Google Scholar, EMBASE and Web of Science from inception to June 2026 [1]. Adult studies evaluating preoperative echocardiographic or vascular ultrasound parameters in relation to hypotension after neuraxial anaesthesia were considered. Case reports, narrative reviews, non-peer-reviewed publications and studies without hypotension as an outcome were excluded. Because of heterogeneity in populations, anaesthetic techniques, outcome definitions and reported indices, a narrative synthesis rather than meta-analysis was performed.

Results: Twelve studies were retained for qualitative synthesis according to the study-selection flow diagram. The strongest and most consistent evidence related to IVC-derived variables, particularly IVCCI, IVC/aorta-related indices and dIVCmax-to-IVCCI ratio. Point-of-care transthoracic echocardiography studies in elderly patients suggested that combined IVC and cardiac indices may help identify vulnerability to post-spinal hypotension. LVEF alone showed limited discriminatory value, especially when preserved. Diastolic indices, particularly mitral inflow E velocity in older patients with mild left ventricular diastolic dysfunction, showed promising predictive value in one retrospective study. Evidence directly supporting GLS as an independent predictor of hypotension after neuraxial anaesthesia was sparse; in the

available studies, GLS was not established as superior to IVC or diastolic indices.
Conclusion: Preoperative ultrasound assessment can contribute to risk stratification before neuraxial anaesthesia, but the evidence is not strong enough to recommend routine GLS assessment for this indication. Current evidence is strongest for IVC-based assessment and selected diastolic parameters in elderly and high-risk patients. Future prospective studies should directly compare GLS, LVEF, diastolic indices and IVC-derived parameters using standardized definitions of hypotension and clinically meaningful outcomes.
Keywords: spinal anaesthesia; neuraxial anaesthesia; hypotension; echocardiography; ejection fraction; global longitudinal strain; inferior vena cava; point-of-care ultrasound; diastolic dysfunction.

INTRODUCTION

Neuraxial anaesthesia is central to contemporary perioperative practice for obstetric, urological, lower abdominal and lower limb surgery. Hypotension after spinal or epidural anaesthesia is clinically important because it may reduce coronary, cerebral, renal and uteroplacental perfusion, increase vasopressor requirement and complicate recovery in frail or cardiovascularly vulnerable patients. The mechanism is multifactorial: sympathetic blockade reduces systemic vascular resistance and venous return, while older patients or those with cardiac disease may have limited ability to augment stroke volume and maintain cardiac output.[3,21]

Preoperative risk assessment often relies on age, baseline blood pressure, comorbidities, American Society of Anesthesiologists physical status, anticipated block height and local anaesthetic dose. These variables are useful but do not directly quantify central volume status or myocardial reserve. Echocardiography and vascular ultrasound are attractive because they may provide bedside information on systolic function, diastolic filling, right ventricular performance and venous capacitance before sympathetic blockade occurs.

LVEF is widely reported and readily understood, but it is load-dependent and may remain normal despite clinically relevant diastolic dysfunction or subclinical myocardial impairment. GLS derived from speckle-tracking echocardiography can detect longitudinal myocardial dysfunction before LVEF declines and has prognostic value in several cardiovascular settings.[2] However, extrapolating this value to neuraxial anaesthesia-induced hypotension is not straightforward. A parameter that predicts chronic cardiovascular prognosis may not necessarily predict an acute preload- and vasodilation-mediated event after spinal anaesthesia. The original framing of this review focused on GLS and LVEF. After reference correction and evidence reappraisal, the more scientifically defensible question is broader: which preoperative echocardiographic or ultrasound-derived parameters have evidence for predicting hypotension after neuraxial anaesthesia, and where do GLS and LVEF fit within that evidence?

2. Objectives

1. To evaluate evidence for preoperative echocardiographic and ultrasound-derived assessment in predicting hypotension after spinal or epidural anaesthesia.
2. To summarize the predictive value of LVEF, GLS, LV diastolic indices and IVC-derived parameters.
3. To identify whether GLS has been directly validated against LVEF or IVC indices for this clinical question.
4. To identify methodological gaps that should be addressed before these measures can be recommended for routine perioperative risk stratification.

3. PICO Framework

Component	Definition
Population	Adults aged 18 years or older undergoing surgery or obstetric procedures under spinal, epidural or combined spinal-epidural anaesthesia.
Index tests	Preoperative or prespinal echocardiographic/ultrasound variables: LVEF, GLS or other strain parameters, LV diastolic indices, stroke volume/cardiac output indices, IVC collapsibility index, IVC diameter and IVC/aorta-derived ratios.
Comparator	Alternative echocardiographic indices, standard clinical assessment, or patients without subsequent hypotension.
Outcome	Hypotension after neuraxial anaesthesia, as defined by included studies: absolute SBP/MAP threshold, relative decline from baseline, vasopressor requirement or composite haemodynamic instability.

MATERIALS AND METHODS

4.1 Design and reporting standard

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. The protocol was registered prospectively in PROSPERO (CRD420261286057). Because the included studies used different populations, hypotension definitions, ultrasound techniques and statistical outputs, the evidence was synthesized narratively rather than pooled quantitatively.

4.2 Search strategy

The search was conducted across PubMed/MEDLINE, Scopus, Google Scholar, EMBASE and Web of Science from database inception to June 2026. Reference lists of included articles and relevant reviews were hand-searched. Search terms combined three domains: neuraxial technique, hypotension outcome and echocardiographic or ultrasound index test.

Example search string: ("spinal anesthesia" OR "spinal anaesthesia" OR "neuraxial anesthesia" OR "neuraxial anaesthesia" OR "epidural anesthesia" OR "epidural anaesthesia" OR "subarachnoid block") AND ("hypotension" OR "hemodynamic instability" OR "vasopressor") AND ("echocardiography" OR "ejection fraction" OR "global longitudinal strain" OR "speckle tracking" OR "diastolic dysfunction" OR "inferior vena cava" OR "IVC collapsibility" OR "caval aorta index").

4.3 Eligibility criteria

Inclusion Criteria: Adult patients; neuraxial anaesthesia; preoperative or prespinal echocardiographic/ultrasound index test; hypotension or vasopressor requirement as an outcome; peer-reviewed observational cohort, case-control or interventional evidence where extractable diagnostic data were available.

Exclusion Criteria: Paediatric studies; studies under general anaesthesia alone; studies without hypotension as an outcome; case reports or very small case series; narrative reviews; letters without primary data; non-peer-reviewed material; articles where the index test could not be separated from the intervention or outcome.

4.4 Data extraction and quality appraisal

For each eligible study, data were extracted on design, population, sample size, anaesthetic technique, ultrasound or echocardiographic parameters, timing of measurement, definition of hypotension, diagnostic estimates and main conclusions. Risk of bias was appraised conceptually using domains adapted from QUADAS-2 and ROBINS-I: patient selection, measurement of index test, outcome definition, confounding, blinding, completeness of data and applicability to clinical practice.

RESULTS

5.1 Study selection

The search strategy identified 75 records. After duplicate removal, 62 records were screened by title and abstract. Twenty-two records were excluded at screening because they were not relevant to the PICO framework. Forty full-text articles were assessed for eligibility; 28 were excluded for reasons including case report or case series design, narrative or non-systematic review, preprint status, non-reporting of GLS or LVEF/ultrasound-relevant variables, absence of neuraxial anaesthesia, absence of hypotension outcome or duplication/other reasons. Twelve studies were included in the qualitative synthesis. The study-selection process is shown in Figure 1.

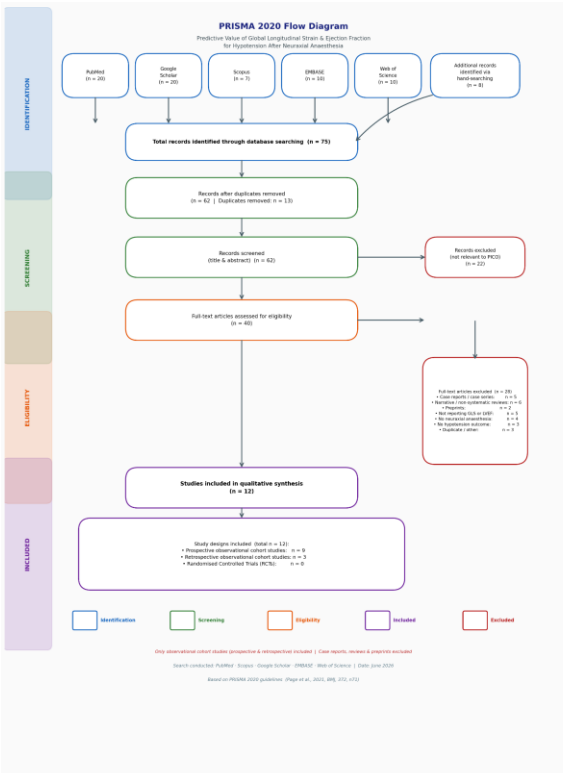

Figure 1: PRISMA 2020 flow diagram for study selection

5.2 Characteristics of included studies

The included literature was heterogeneous. Most studies were single-centre observational studies and sample sizes were generally modest. Populations included elderly orthopaedic or trauma patients, older urological patients, adults undergoing elective lower abdominal or lower limb surgery, and pregnant women undergoing caesarean delivery. Spinal anaesthesia was the dominant neuraxial technique. Hypotension definitions varied across studies, including absolute systolic blood pressure thresholds, relative falls from baseline, mean arterial pressure thresholds and vasopressor requirement.

Table 2: Summary of key included studies

Study	Design and population	Index test(s)	Main finding
Saranteas et al., 2019	Prospective observational; elderly lower limb orthopaedic/vascular surgery; spinal anaesthesia; n=70 analysed.	TTE: LVEF, GLS, TAPSE, E/e', SVI, IVC measurements and dIVCmax-to-IVCCI ratio.	dIVCmax-to-IVCCI ratio and age were the strongest predictors; GLS was assessed but not established as the principal

			predictor.
Moschovaki et al., 2023	Prospective observational; elderly orthopaedic-trauma patients with cardiac disease and reduced LVEF; n=61.	TTE: LVEF, SVI, PVR, E/e', RV indices, IVCCI and dIVCmax-to-IVCCI ratio.	dIVCmax-to-IVCCI ratio <48 had the best diagnostic performance among echocardiographic variables.
Park et al., 2024	Retrospective observational; patients >=65 years with grade I LV diastolic dysfunction undergoing urological surgery; n=163.	Preoperative TTE within 6 months: mitral inflow E velocity and other LV diastolic indices.	Mitral inflow E velocity <=60 cm/s predicted spinal anaesthesia-induced hypotension with AUC 0.819.
Wang et al., 2026	Multicentre predictive-model study in older patients receiving spinal anaesthesia.	Clinical variables plus TTE indices including IVSd, e' and E/e'.	Nomogram incorporated age, BMI, bupivacaine dose, block level, baseline SBP, hypertension and echocardiographic diastolic variables.
Salama and Elkashlan, 2019	Prospective observational; adult patients undergoing spinal anaesthesia.	IVCCI and caval/aorta index.	IVC-derived indices were proposed as predictors of post-spinal hypotension.
Maciuliene et al., 2018	Prospective study; elective knee replacement under spinal anaesthesia; n=60.	Serial IVC diameters and IVC collapsibility index.	IVC-CI did not predict hypotension or bradycardia; AUC values were <0.7.
Singh/Anand et al., 2019	Prospective observational; elective caesarean section under spinal anaesthesia; n=45.	IVCCI before spinal anaesthesia.	IVCCI did not reliably predict post-spinal hypotension in parturients.
Elbadry and Sabaa, 2022	Prospective observational; pregnant women undergoing caesarean section.	IVCCI and internal jugular vein collapsibility index.	IVCCI and IJVCI predicted post-spinal hypotension, with slight superiority of IVCCI.
Chowdhury et al., 2022	Prospective observational; spontaneously breathing patients under spinal anaesthesia.	IVCCI and carotid artery peak systolic velocity variation.	Both IVCCI and carotid-flow variation were evaluated as predictors of post-spinal hypotension.
Sethi et al., 2023	Prospective observational; ASA I/II adults receiving central neuraxial block; n=100.	Preoperative IVCCI.	Preoperative IVCCI was useful for predicting hypotension after central neuraxial block.
Lal et al., 2023	Prospective blinded observational; spinal anaesthesia; Indian Journal of Anaesthesia.	IVCCI and caval aorta index.	IVCCI and caval/aorta index were associated with spinal anaesthesia-induced hypotension; IVCCI was among the strongest predictors.
Yotsuya et al., 2024	Retrospective case-control; elderly hip fracture repair under spinal anaesthesia managed by orthopaedic surgeons.	Clinical and perioperative background factors; not a GLS study.	Emphasized volume deficit and extensive sympathetic blockade as likely contributors to intraoperative hypotension.

5.3 LVEF and conventional systolic function

LVEF was included in several echocardiographic studies, but it was rarely the best-performing predictor. In the study by Saranteas et al., multiple echocardiographic parameters were assessed, including LVEF and GLS; however, the dIVCmax-to-IVCCI ratio and age were the best predictors of spinal-induced hypotension. In elderly patients with cardiac disease and reduced LVEF, Moschovaki et al. similarly found that an IVC-derived composite ratio outperformed several conventional cardiac indices.[5,6] These findings suggest that LVEF identifies a vulnerable cardiovascular phenotype but is not sufficient as a stand-alone predictor of post-spinal hypotension.

This is physiologically plausible. Spinal anaesthesia reduces venous return and systemic vascular resistance. A patient with reduced LVEF may tolerate these changes poorly, but many patients with preserved LVEF may also develop hypotension because of low preload, impaired diastolic filling, high block level, autonomic dysfunction or relative hypovolaemia. Therefore, a model based only on LVEF is likely to miss clinically important risk.

5.4 LV diastolic indices

Diastolic reserve may be particularly relevant in older patients. Park et al. studied older patients with mild LV diastolic dysfunction undergoing spinal anaesthesia for urological surgery and found that mitral inflow E velocity was an independent predictor of spinal anaesthesia-induced hypotension. A threshold of approximately 60 cm/s showed good discrimination. Wang et al. also incorporated echocardiographic diastolic variables into a prediction model for older patients.[7,8] These studies support the concept that diastolic filling and ventricular compliance may matter more than LVEF in selected geriatric populations.

The limitation is that diastolic variables are sensitive to preload, rhythm, age, measurement technique and timing of echocardiography. Therefore, they should be interpreted in a clinical context rather than as universal cut-off values.

5.5 Global longitudinal strain

GLS was the most overinterpreted element in the original manuscript. The corrected evidence base does not show that GLS is an established predictor of post-neuraxial hypotension. GLS was assessed in at least one relevant echocardiographic study, but it did not emerge as the dominant predictor compared with IVC-derived indices and age. No robust head-to-head study was found that specifically validated GLS versus LVEF for predicting hypotension after spinal anaesthesia in broad non-cardiac surgical populations.

GLS remains scientifically plausible because it can detect subclinical myocardial dysfunction in patients with preserved LVEF. However, post-spinal hypotension is an acute event dominated by sympathetic blockade, venous pooling, preload reduction and compensatory autonomic responses. A marker of longitudinal myocardial deformation may contribute to risk prediction, but it should be tested alongside IVC indices, diastolic parameters, baseline blood pressure, block height, age, frailty and vasopressor strategy.

5.6 IVC-derived predictors and preload assessment

IVC-based assessment had the largest body of direct evidence. Several studies reported that higher IVCCI or abnormal IVC/aorta-derived indices predicted hypotension after spinal or central neuraxial block. Salama and Elkashlan, Chowdhury et al., Sethi et al. and Lal et al. supported the predictive utility of IVC-derived variables in adult surgical populations. In elderly patients, Saranteas et al. and Moschovaki et al. found that a combined dIVCmax-to-IVCCI ratio may outperform IVCCI alone and other echocardiographic measures.[5,6,9,14-16]

However, evidence is not uniform. Maciuliene et al. found that IVC-CI did not predict hypotension or bradycardia during spinal anaesthesia in spontaneously breathing patients undergoing elective knee replacement. Singh/Anand et al. found poor predictive performance in obstetric patients, whereas Elbadry and Sabaa reported better performance of IVCCI in a caesarean population.[10,12,13] These differences likely reflect patient population, position, respiratory mechanics, aortocaval compression, fluid strategy, local anaesthetic dose and definitions of hypotension.

5.7 Risk of bias and certainty of evidence

Overall certainty was low to moderate.[19,20] The most important limitations were single-centre design, modest sample size, inconsistent hypotension definitions, variable time points for ultrasound assessment, lack of blinding in some studies, and limited external validation. Diagnostic accuracy studies were often exploratory and cut-offs were not consistently validated in independent cohorts. The certainty for GLS was very low because direct evidence was sparse.

Table 3: Evidence certainty by predictor group

Predictor group	Evidence strength	Main reason	Clinical interpretation
IVC indices	Moderate diagnostic signal but heterogeneous	Multiple studies; some positive, some negative; pooled certainty limited by heterogeneity.	Potentially useful as bedside risk stratification in selected patients; cut-offs should not be universal.
dIVCmax-to-IVCCI ratio	Promising in elderly high-risk patients	Two relevant TTE studies suggested better performance than IVCCI alone.	Requires replication; may be more informative than collapsibility alone.
LVEF	Low as stand-alone predictor	Useful for overt systolic dysfunction but limited sensitivity when preserved.	Should be interpreted with diastolic and preload indices.
LV diastolic indices	Low to moderate	Mitral inflow E velocity and E/e' appear clinically plausible, especially in older patients.	Needs prospective validation and standardized timing.
GLS	Very low for this specific outcome	Theoretical and background echocardiographic value is strong, but direct neuraxial hypotension data are limited.	Should be treated as a research variable rather than routine predictor.

DISCUSSION

6.1 Principal findings

This review found that the current evidence does not justify a conclusion that GLS is superior to LVEF for predicting hypotension after neuraxial anaesthesia. Instead, the evidence points toward a more practical and physiologically coherent message: hypotension after spinal anaesthesia is better predicted by parameters reflecting preload, diastolic reserve and cardiovascular compensatory capacity than by LVEF alone.

The most consistent direct evidence concerns IVC-derived variables, although even this evidence is heterogeneous.[19,20] In selected elderly patients, the dIVCmax-to-IVCCI ratio may perform better than IVCCI alone because it combines a static IVC diameter component with respiratory collapsibility. In older patients with mild diastolic dysfunction, mitral inflow E velocity may identify limited filling reserve. GLS remains attractive but insufficiently validated for this specific perioperative endpoint.

6.2 Why GLS should be discussed cautiously

GLS is a sensitive marker of myocardial deformation and may detect subclinical left ventricular dysfunction before LVEF declines. This property makes it valuable in cardiology and perioperative risk assessment more broadly. However, neuraxial hypotension is not purely a myocardial contractility problem. It is usually initiated by sympathetic blockade, decreased systemic vascular resistance, venous pooling and reduced venous return. Therefore, GLS may be only one component of risk, and its added value over

IVC parameters, diastolic variables and clinical predictors remains unproven.

A manuscript intended for a good indexed journal should not present GLS as clinically superior unless supported by direct comparative data. The safer and more accurate conclusion is that GLS is a promising research variable requiring prospective validation.

6.3 Clinical implications

For elderly orthopaedic or trauma patients: preoperative or prespinal POCUS assessment of IVC and focused cardiac function may identify patients vulnerable to hypotension, especially when cardiac disease or frailty is present.

For older patients with known or suspected diastolic dysfunction: available TTE reports should not be reduced to LVEF alone; mitral inflow and tissue Doppler parameters may add useful information.

For obstetric patients: IVC interpretation is more complex because aortocaval compression, maternal positioning and pregnancy physiology alter venous return. Obstetric extrapolation from non-obstetric studies should be avoided.

For GLS: routine use solely to predict post-spinal hypotension cannot currently be recommended; it may be considered in research protocols or high-risk cardiac populations where advanced echocardiography is already being performed.

6.4 Limitations of this review

The available studies were heterogeneous in population, anaesthetic technique, local anaesthetic dose and hypotension definition.

Most studies were single-centre and underpowered for robust diagnostic modelling.

Several studies reported different cut-offs for IVCCI or related measures, limiting direct clinical translation.

The evidence base for GLS was sparse and did not allow definitive comparison with LVEF.

Some potentially relevant studies were not suitable for inclusion because they were reviews, non-neuraxial anaesthesia studies, case reports or studies without extractable hypotension outcome data.

6.5 Future research

Future studies should be prospective, adequately powered and designed specifically to compare GLS, LVEF, diastolic indices, IVC-derived variables and clinical predictors in the same patient cohort. Hypotension should be defined using both absolute and relative criteria, and outcomes should include vasopressor dose, duration of hypotension, myocardial injury, acute kidney injury, delirium, maternal-fetal outcomes and length of stay. Predictive models should undergo external validation and decision-curve analysis before being recommended for routine practice.

CONCLUSION

Preoperative echocardiographic and ultrasound-derived assessment may improve risk stratification for hypotension after neuraxial anaesthesia, particularly in elderly and cardiovascularly vulnerable patients. Current evidence is strongest for IVC-derived indices and selected diastolic parameters, while LVEF alone has limited predictive sensitivity. GLS is biologically plausible but insufficiently validated for this specific clinical outcome. For a journal-ready conclusion, GLS should be presented as a promising research variable rather than an established predictor. The most defensible clinical approach is multimodal assessment combining clinical risk factors, block-related variables, IVC-derived preload assessment and focused echocardiographic evaluation of systolic and diastolic function.

Declarations

Funding: No external funding declared.

Conflicts of interest: The authors should declare any relevant conflicts of interest. If none, state: The authors declare no conflicts of interest.

Ethical approval: Not applicable for a review article.

Data availability: All data are derived from published studies.

Author contribution statement: To be completed according to journal requirements.

Use of artificial intelligence: Language editing and manuscript restructuring assistance was used. All scientific content, references and final responsibility should be verified and approved by the authors before submission.

REFERENCES

1. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71.
2. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr. 2015;28(1):1-39.e14. doi:10.1016/j.echo.2014.10.003.
3. Lee JE, George RB, Habib AS. Spinal-induced hypotension: incidence, mechanisms, prophylaxis, and management: summarizing 20 years of research. Best Pract Res Clin Anaesthesiol. 2017;31(1):57-68. doi:10.1016/j.bpa.2017.01.001.
4. Kinsella SM, Carvalho B, Dyer RA, Fernando R, McDonnell N, Mercier FJ, et al. International consensus statement on the management of hypotension with vasopressors during caesarean section under spinal anaesthesia. Anaesthesia. 2018;73(1):71-92. doi:10.1111/anae.14080.
5. Saranteas T, Spiliotaki H, Koliantzaki I, Koutsomanolis D, Kopanaki E, Papadimos T, et al. The utility of echocardiography for the prediction of spinal-induced hypotension in elderly patients: inferior vena cava assessment is a key player. J Cardiothorac Vasc Anesth. 2019;33(9):2421-2427. doi:10.1053/j.jvca.2019.02.032.
6. Moschovaki N, Saranteas T, Spiliotaki E, Giannoulis D, Anagnostopoulos D, Talliou C, et al. Point of care transthoracic echocardiography for the prediction of post-spinal anesthesia hypotension in elderly patients with cardiac diseases and left ventricular dysfunction: inferior vena cava and post-spinal anesthesia hypotension in elderly patients. J Clin Monit Comput. 2023;37(5):1207-1218. doi:10.1007/s10877-023-00981-y.

7. Park EJ, Cho AR, Kim HJ, Lee HJ, Jeon S, Baik J, et al. Preoperative echocardiography as a predictor of spinal anesthesia-induced hypotension in older patients with mild left ventricular diastolic dysfunction: a retrospective observational study. Anesth Pain Med. 2024;19(2):134-143. doi:10.17085/apm.23161.
8. Wang B, et al. A nomogram for predicting the risk of spinal anesthesia-induced hypotension in older patients. Diagnostics. 2026;16(4):557. doi:10.3390/diagnostics16040557.
9. Salama ER, Elkashlan M. Pre-operative ultrasonographic evaluation of inferior vena cava collapsibility index and caval aorta index as new predictors for hypotension after induction of spinal anaesthesia: a prospective observational study. Eur J Anaesthesiol. 2019;36(4):297-302. doi:10.1097/EJA.0000000000000956.
10. Maciuliene A, Gelmanas A, Jaremko I, Tamosiunas R, Smailys A, Macas A. Measurements of inferior vena cava diameter for prediction of hypotension and bradycardia during spinal anesthesia in spontaneously breathing patients during elective knee joint replacement surgery. Medicina (Kaunas). 2018;54(3):49. doi:10.3390/medicina54030049.
11. Aslan Y, Arslan G, Saracoglu KT, Eler Cevik B. The effect of ultrasonographic measurement of vena cava inferior diameter on the prediction of post-spinal hypotension in geriatric patients undergoing spinal anaesthesia. Int J Clin Pract. 2021;75(10):e14622. doi:10.1111/ijcp.14622.
12. Anand RK, Singh Y, Gupta S, Chowdhury SR, Maitra S, Baidya DK, et al. Role of IVC collapsibility index to predict post spinal hypotension in pregnant women undergoing caesarean section: an observational trial. Saudi J Anaesth. 2019;13(4):312-317. doi:10.4103/sja.SJA_121_19.
13. Elbadry AA, Sabaa MAA. Pre-operative ultrasonographic evaluation of the internal jugular vein collapsibility index and inferior vena cava collapsibility index to predict post spinal hypotension in pregnant women undergoing caesarean section. Anesth Pain Med. 2022;12(1):e121648. doi:10.5812/aapm.121648.
14. Chowdhury SR, Baidya DK, Maitra S, Singh AK, Rewari V, Anand RK. Assessment of role of inferior vena cava collapsibility index and variations in carotid artery peak systolic velocity in prediction of post-spinal anaesthesia hypotension in spontaneously breathing patients: an observational study. Indian J Anaesth. 2022;66(2):100-106. doi:10.4103/ija.ija_828_21.
15. Sethi D, Jadhav VL, Garg G. Role of inferior vena cava collapsibility index in the prediction of hypotension associated with central neuraxial block: a prospective observational study. J Ultrasound Med. 2023;42(9):1977-1985. doi:10.1002/jum.16214.
16. Lal J, Jain M, Rahul, Singh AK, Bansal T, Vashisth S. Efficacy of inferior vena cava collapsibility index and caval aorta index in predicting the incidence of hypotension after spinal anaesthesia - a prospective, blinded, observational study. Indian J Anaesth. 2023;67(6):523-529. doi:10.4103/ija.ija_890_22.
17. Yotsuya K, Sarukawa J, Yamazaki K, Yasuda T, Oishi T, Ushirozako H, et al. Background factors for intra-operative hypotension during hip fracture repair surgery in the elderly under spinal anesthesia managed by orthopedic surgeons: a retrospective case-control study. Injury. 2024;55(6):111549. doi:10.1016/j.injury.2024.111549.
18. Roy S, Kothari N, Goyal S, Sharma A, Kumar R, Kaloria N, et al. Preoperative assessment of inferior vena cava collapsibility index by ultrasound is not a reliable predictor of post-spinal anesthesia hypotension. Braz J Anesthesiol. 2023;73(4):385-392. doi:10.1016/j.bjane.2022.04.001.
19. Chang YJ, Liu CC, Huang YT, Wu JY, Hung KC, Liu PH, et al. Assessing the efficacy of inferior vena cava collapsibility index for predicting hypotension after central neuraxial block: a systematic review and meta-analysis. Diagnostics. 2023;13(17):2819. doi:10.3390/diagnostics13172819.
20. Chowdhury SR, Datta PK, Maitra S, Rawat D, Baidya DK, Roy A, et al. The use of preoperative inferior vena cava ultrasound to predict anaesthesia-induced hypotension: a systematic review. Anaesthesiol Intensive Ther. 2023;55(1):18-31. doi:10.5114/ait.2023.125310.
21. Hofhuizen C, Lemson J, Snoeck M, Scheffer GJ. Spinal anesthesia-induced hypotension is caused by a decrease in stroke volume in elderly patients. Local Reg Anesth. 2019;12:19-26. doi:10.2147/LRA.S193925.
22. Ni TT, Zhou ZF, He B, Zhou QH. Inferior vena cava collapsibility index can predict hypotension and guide fluid management after spinal anesthesia. Front Surg. 2022;9:831539. doi:10.3389/fsurg.2022.831539.