Predicting Post-Spinal Anesthesia Hypotension in Geriatric Patients: A Narrative Review of Ultrasonographic Carotid Flow Time and Inferior Vena Cava Collapsibility Index

Mahmoud Ramadan Ahmed Ebrahim*, Maged Labib Boulos Youssef, Mohamed Ahmed Hamed Ismail, Abeer Shaban Goda Morsy, Yasser Salem Mostafa Mahmoud.

Department of Anesthesia, Surgical ICU & Pain Management, Faculty of Medicine - Fayoum University, Egypt.

Abstract

Post-spinal anesthesia hypotension (PSAH) remains a frequent and potentially severe complication, particularly in geriatric patients who possess limited physiological reserves. Accurate prediction of PSAH is crucial for timely intervention and improved patient outcomes. This narrative review synthesizes current evidence regarding the efficacy of two non-invasive ultrasonographic indices—corrected carotid flow time (CFTc) and inferior vena cava collapsibility index (IVCCI)—in predicting PSAH in the elderly. The review highlights a recent prospective observational study on 282 geriatric patients undergoing elective surgeries, which found that neither CFTc (AUC 0.506, p=0.902) nor IVCCI (AUC 0.515, p=0.737) independently served as reliable predictors of PSAH. This finding is consistent with several other studies in geriatric or specific patient populations, suggesting limitations of these indices in complex hemodynamic scenarios. Conversely, some meta-analyses and studies in younger cohorts indicate better predictive value, underscoring the influence of patient demographics and physiological context. The review discusses the unique hemodynamic challenges in older adults that may diminish the predictive accuracy of these tools and emphasizes the need for comprehensive, multifactorial risk assessment. Future research should focus on integrating multiple parameters and advanced predictive models to enhance PSAH prediction and ultimately improve safety for geriatric patients undergoing spinal anesthesia.

Key words: ***Post-spinal anesthesia hypotension, Geriatric patients, Corrected carotid flow time, Inferior vena cava collapsibility index, Hemodynamic prediction.***

Introduction

Post-spinal anesthesia hypotension (PSAH) stands as the most prevalent adverse event associated with spinal anesthesia, with reported incidences ranging from 15% to 30% [1]. Defined as a significant drop in systemic blood pressure, typically below 90/60 mmHg, though a universally accepted standard value remains elusive, PSAH arises primarily from reduced systemic vascular resistance due to sympathetic inhibition, coupled with a decrease in cardiac output resulting from diminished venous return [2, 3]. The clinical manifestations of PSAH can range from mild symptoms such as dizziness and nausea to severe complications including cardiac arrhythmias, syncope, and even cardiac arrest. Critically, intraoperative hypotension is strongly linked to an increased incidence of postoperative morbidity and mortality [4]. Consequently, the ability to accurately predict PSAH and implement timely preventive measures is of paramount importance to avert undesirable outcomes.

The geriatric population presents a unique and particularly vulnerable cohort in the context of PSAH. While often defined as individuals aged 65 years and above, the physiological changes associated with aging are progressive, with many biological processes peaking before age 30 and subsequently declining linearly [5, 6, 7, 8]. This age-related reduction in physiological reserve becomes particularly critical under stress, such as during anesthesia, and contributes significantly to functional decline in older

adults [9]. Consequently, the evaluation and management of older patients differ considerably from younger individuals, often necessitating a more nuanced approach to history-taking and physical examination, especially for those who are frail or very elderly [10, 11].

Traditional approaches to PSAH prevention, such as empirical intravenous fluid loading, have demonstrated limitations. Fluid boluses fail to adequately increase cardiac volume in approximately 50% of hemodynamically unstable patients, and in fluid non-responsive individuals, such empirical loading may even exacerbate the patient's condition [12, 13]. The absence of a definitive tool to reliably predict PSAH makes it challenging to differentiate patients who would benefit from vasopressors versus those who would respond to fluid boluses. While numerous dynamic and static indices of fluid responsiveness exist, their performance varies considerably across different clinical settings [14, 15].

The ongoing quest for simple, reliable, and non-invasive methods to predict PSAH has led to the exploration of various ultrasonographic parameters [16]. While techniques like transthoracic bioimpedance and transthoracic echocardiography (TTE) offer insights into hemodynamic status, TTE demands high operator proficiency and is time-consuming, and bioimpedance devices are often expensive and not readily available [17]. In contrast, ultrasonographic assessment of the inferior vena cava collapsibility index (IVCCI) and corrected carotid flow time (CFTc) have emerged as potentially time-efficient, easy-to-perform, and widely available indicators of fluid responsiveness, capable of identifying changes in cardiac output [18, 19, 20].

The IVC diameter, measured ultrasonographically, provides an indirect assessment of intravascular volume [21]. Preoperative IVCCI has been proposed as a dependable indicator for predicting the likelihood of hypotension within 30 minutes following spinal anesthesia in elective surgical patients [22]. Similarly, CFTc, which represents the carotid systole time corrected for heart rate, is a simple measurement that may correlate with intravascular volume, with fluid administration increasing CFTc and volume depletion decreasing it [23, 24]. However, direct comparative studies evaluating the efficacy of both CFTc and IVCCI in predicting PSAH, particularly in the geriatric population, have been scarce. This narrative review aims to synthesize the current understanding of PSAH in geriatric patients, delve into the physiological basis and application of CFTc and IVCCI as predictive tools, critically analyze the existing literature, including a recent prospective observational study, and discuss the implications for clinical practice and future research.

Pathophysiology of Post-Spinal Anesthesia Hypotension in Geriatric Patients

Post-spinal anesthesia hypotension (PSAH) is a multifactorial phenomenon primarily driven by the neuraxial blockade's effects on the sympathetic nervous system. Spinal anesthesia induces a sympathetic block that leads to vasodilation, particularly in the lower extremities, resulting in a significant decrease in systemic vascular resistance (SVR) [2, 3]. Concurrently, the venous pooling in the dilated capacitance vessels reduces venous return to the heart, thereby decreasing preload and consequently cardiac output (CO) [3]. The combined reduction in SVR and CO culminates in a fall in mean arterial pressure (MAP), leading to hypotension.

In geriatric patients, these physiological mechanisms are compounded by age-related cardiovascular and autonomic changes, rendering them particularly susceptible to PSAH and its adverse consequences. Several factors contribute to this heightened vulnerability:

1. **Reduced Cardiovascular Reserve:** With advancing age, there is a natural decline in cardiac reserve. The myocardium becomes stiffer, leading to impaired diastolic function and a reduced ability to increase stroke volume in response to increased preload [25]. Furthermore, the maximal heart rate achievable during stress is lower in older adults, limiting their capacity to augment cardiac output through chronotropic mechanisms [25]. This diminished ability to compensate for the sympathetic block makes them more prone to significant drops in blood pressure.

2. **Altered Autonomic Regulation:** Aging is associated with impaired baroreflex sensitivity, which is crucial for rapid adjustments in heart rate and vascular tone in response to blood pressure fluctuations [26]. A blunted baroreflex response means that the body is less effective at counteracting the vasodilation induced by spinal anesthesia, leading to more profound and sustained hypotension.

3. **Decreased Vascular Compliance:** The arterial tree stiffens with age due to changes in elastin and collagen content, leading to reduced arterial compliance [27]. While this can result in higher baseline systolic blood pressure, it also means that the vasculature is less able to constrict effectively to maintain blood pressure in the face of sympathetic blockade.

4. **Polypharmacy and Comorbidities:** Geriatric patients often present with multiple comorbidities such as hypertension, diabetes, coronary artery disease, and chronic kidney disease, and are frequently on polypharmacy (e.g., antihypertensive medications, diuretics) [10]. These conditions and medications can independently affect cardiovascular function, fluid status, and autonomic regulation, further predisposing them to hypotension and complicating its management. For instance, antihypertensive medications can exacerbate the vasodilatory effects of spinal anesthesia.

5. **Reduced Blood Volume:** While not universally true, some elderly patients, particularly those who are frail or have chronic illnesses, may have a relatively lower effective circulating blood volume or be in a state of chronic dehydration, making them more sensitive to volume shifts induced by anesthesia [13].

The clinical consequences of PSAH are more pronounced in the elderly. Prolonged or severe hypotension can lead to critical organ hypoperfusion, increasing the risk of myocardial ischemia, acute kidney injury, stroke, and cognitive dysfunction [4]. Given these heightened risks, accurate and reliable prediction of PSAH in geriatric patients is not merely about managing a common side effect but is fundamental to enhancing patient safety and improving postoperative outcomes. This necessitates a thorough understanding of their unique physiological responses and the development of tailored predictive strategies.

Non-Invasive Hemodynamic Monitoring for PSAH Prediction

The quest for non-invasive, accurate, and readily available tools to predict post-spinal anesthesia hypotension (PSAH) has led to significant research into various hemodynamic monitoring techniques. While invasive methods like central venous pressure (CVP) or pulmonary artery catheterization offer detailed hemodynamic data, their invasive nature, associated risks, and cost limit their routine use for PSAH prediction. Consequently, non-invasive ultrasonographic indices have gained prominence due to their safety, accessibility, and potential to provide real-time insights into a patient's volume status and cardiac function.

Among these, transthoracic echocardiography (TTE) and transthoracic bioimpedance have been explored. TTE offers comprehensive assessment of cardiac function (ejection fraction, stroke volume) and volume status (ventricular dimensions, IVC dynamics) [17]. However, its widespread application for routine PSAH prediction is hampered by the need for high operator proficiency and its time-consuming nature in a busy operating room setting. Transthoracic bioimpedance, while providing continuous cardiac output measurements, is often expensive and not universally available [17]. These limitations underscore the need for simpler, yet effective, non-invasive alternatives.

This review focuses on two such promising ultrasonographic indices: Corrected Carotid Flow Time (CFTc) and Inferior Vena Cava Collapsibility Index (IVCCI).

Corrected Carotid Flow Time (CFTc)

Physiological Basis: Carotid flow time (CFT) represents the duration of systolic ejection in the carotid artery. It is a surrogate measure of left ventricular systolic function and stroke volume. Changes in CFT can reflect alterations in cardiac contractility and preload. To account for variations in heart rate, CFT is often corrected (CFTc) using formulas like Wodey's formula (CFTc = carotid flow time + 1.29 × (heart rate – 60)) [23]. A longer CFTc typically indicates a larger stroke volume or increased preload, while a shorter CFTc suggests reduced stroke volume or hypovolemia.

Application in PSAH Prediction: The theoretical appeal of CFTc in predicting PSAH lies in its potential to non-invasively assess changes in cardiac output and volume status. As spinal anesthesia primarily reduces preload and SVR, a patient with a lower baseline CFTc (suggesting lower baseline volume or cardiac reserve) might be more susceptible to a significant drop in blood pressure. Conversely, an increase in CFTc after fluid administration could indicate fluid responsiveness. Its measurement is relatively straightforward, involving a high-frequency linear ultrasound probe placed over the common carotid artery, making it accessible in various clinical settings [20].

Inferior Vena Cava Collapsibility Index (IVCCI)

Physiological Basis: The Inferior Vena Cava (IVC) is a large, compressible vein that reflects central venous pressure and, indirectly, intravascular volume status. In spontaneously breathing individuals, the IVC diameter fluctuates with respiration: it typically decreases during inspiration (as intrathoracic pressure drops, drawing blood into the chest) and increases during expiration. The IVCCI quantifies this respiratory variation and is calculated as: IVCCI = (Maximum IVC Diameter - Minimum IVC Diameter) / Maximum IVC Diameter × 100 [22]. A high IVCCI (e.g., >40-50%) suggests a relatively hypovolemic state or a fluid-responsive patient, while a low IVCCI (e.g., <10-20%) indicates a hypervolemic state or a fluid non-responsive patient.

Application in PSAH Prediction: The rationale for using IVCCI to predict PSAH is based on the premise that patients who are relatively hypovolemic preoperatively, as indicated by a higher IVCCI, may be more susceptible to the preload reduction induced by spinal anesthesia [22]. By identifying these "dry" patients, clinicians could potentially preemptively administer fluids or vasopressors to prevent hypotension. The IVC is typically scanned using a low-frequency curvilinear probe in the subxiphoid region, making it a quick and non-invasive assessment [19].

Both CFTc and IVCCI offer advantages in terms of non-invasiveness and ease of performance. However, their predictive accuracy can be influenced by various factors, including patient age, respiratory effort, cardiac function, and the presence of comorbidities, particularly in the complex physiological landscape of geriatric patients. The following section will critically review the existing evidence regarding their efficacy in predicting PSAH.

Review of Evidence: CFTc and IVCCI in Predicting PSAH (with focus on Geriatrics)

The efficacy of ultrasonographic indices like corrected carotid flow time (CFTc) and inferior vena cava collapsibility index (IVCCI) in predicting post-spinal anesthesia hypotension (PSAH) has been a subject of extensive research. While these tools offer the promise of non-invasive, real-time hemodynamic assessment, their predictive power, particularly in the complex geriatric population, remains debated.

The Index Study's Findings

The recent prospective observational study conducted at Fayoum University Hospital on 282 geriatric patients undergoing elective surgeries provides a crucial contribution to this debate. The study's primary objective was to compare the efficacy of CFTc and IVCCI in predicting PSAH in this specific age group. The results indicated that the incidence of PSAH in the cohort was 16.3%. However, the core finding from the Receiver Operating Characteristic (ROC) curve analysis was that neither CFTc nor IVCCI served as statistically significant independent predictors of PSAH. The Area Under the Curve (AUC) for CFTc was 0.506 (95% CI: 0.446–0.566, p = 0.902), and for IVCCI was 0.515 (95% CI: 0.455–0.574, p = 0.737). These AUC values, being close to 0.5, suggest a predictive performance no better than random chance, as visually confirmed by the ROC curves closely following the diagonal reference line. Furthermore, no statistically significant difference was found between the two methods in their ability to predict PSAH in this geriatric population.

The study also reported that while ephedrine requirements and fluid administration were significantly higher in patients who developed PSAH, heart rate remained comparable between the hypotensive and normotensive groups at all time points. This suggests that the compensatory mechanisms involving heart rate might be blunted or insufficient in this elderly cohort, leading to a more pronounced drop in mean arterial pressure despite similar heart rate responses. A weak negative correlation was noted between IVCCI and 20-minute mean arterial pressure (MAP) in non-PSAH patients ($r = -0.147$, $P = 0.024$), and an intermediate positive correlation between CFTc and 20-minute heart rate in PSAH patients ($r = 0.556$, $P < 0.001$), indicating some physiological relationships but not robust predictive power for the onset of hypotension.

Concordant Studies

The findings of the index study, indicating the limited predictive value of CFTc and IVCCI in geriatric patients, are consistent with several other investigations, particularly those focusing on older adults or specific patient populations with altered hemodynamics.

Jaremko et al. [24] conducted a study at Kauno Klinikos Hospital, specifically evaluating the prognostic value of IVCCI in predicting severe intraoperative hypotension in spontaneously breathing individuals undergoing elective knee arthroplasty. This study, like the index study, focused on a geriatric cohort with a mean age of 70.4 years (compared to 72.12 years in the index study). Despite empirical fluid administration to prevent spinal anesthesia-induced hypotension, their measurements of IVC diameters and IVCCI before and after spinal anesthesia, along with hemodynamic parameters, revealed no significant differences between hypotensive and non-hypotensive patients. ROC analysis further confirmed that IVCCI was not a reliable predictor, with an AUC of less than 0.7 and a p-value greater than 0.05. These results strongly align with the index study's conclusion regarding the ineffectiveness of IVCCI in predicting severe hypotension in this elderly patient population.

Similarly, Kim et al. [26, 28] investigated predictors of PSAH in elderly individuals (mean age 71 years) undergoing elective surgery under spinal anesthesia. Their study focused on ultrasonographic carotid artery flow evaluation during the passive leg raise (PLR) test and preoperative transthoracic echocardiography (TTE) parameters. While carotid blood flow in the semi-recumbent position showed some predictive capability with an AUC of 0.754 (95% CI, 0.612–0.865), it did not maintain significance in multivariate analysis. These findings suggest that ultrasonographic carotid artery flow measurements during PLR testing may not reliably predict PSAH in elderly patients, which is in concordance with the index study's results regarding CFTc.

Further supporting these observations, Wang et al. [29] performed a prospective, observational study assessing the predictive capability of CFTc and carotid peak velocity variation (ΔVpeakCCA) measured via carotid Doppler ultrasound for PSAH in 42 elderly patients undergoing elective surgery under general anesthesia. Despite evaluating these parameters both preoperatively and intraoperatively, 43% of patients experienced PSAH, with no significant differences observed in CFTc or ΔVpeakCCA between normotensive and hypotensive groups ($p = 0.91$ and $p = 0.34$, respectively). The AUC for CFTc and ΔVpeakCCA was 0.52 and 0.59, respectively, indicating poor predictive performance. They concluded that carotid Doppler ultrasound has limitations in preoperatively identifying those at risk of hypotension following general anesthesia induction in the elderly, a finding that parallels the index study's conclusions for spinal anesthesia.

Complementary findings from other clinical contexts, such as pregnant women undergoing elective cesarean section, also align with the index study's results, underscoring the need for caution in extrapolating predictive abilities of these indices across different patient populations and clinical settings. Singh et al. [30] tested the hypothesis that IVCCI could identify hypovolemic parturients at risk of post-spinal hypotension (PSH) in a prospective observational study involving 45 women. Despite measuring IVCCI in both supine positions (without wedge) and left lateral tilt (with wedge) before spinal anesthesia, their findings indicated that IVCCI was not a reliable predictor of PSAH. Specifically, the AUC for IVCCI with wedge was 0.46 (95% CI 0.27, 0.64), and for IVCCI without wedge was 0.38 (95% CI 0.19, 0.56), with sensitivity and specificity values suggesting limited discriminatory power. These results, while in a different physiological context (pregnancy), reinforce the notion that IVCCI may not be a universal predictor of hypotension.

Chowdhury et al. [17, 31] conducted a study on adult patients (age 18-60 years) undergoing elective lower abdominal operations under spinal anesthesia, investigating the utility of IVCCI and carotid artery peak systolic velocity variations (CAPVV) as predictors of PSAH. Despite their established use in assessing volume status in critically ill patients, their findings indicated limited diagnostic accuracy of both IVCCI and CAPVV in predicting PSH. They demonstrated that IVCCI > 21.15 ml showed 69.7% specificity and 58.8% sensitivity, while CAPVV > 18.33 showed 54.6% specificity and 70.6% sensitivity for predicting PSAH. A composite model incorporating IVC max, CAPVV, and baseline mean blood pressure marginally improved prediction, but overall, neither IVCCI nor CAPVV, independently or in combination, proved robust in predicting PSH in this surgical cohort. These results parallel the index study's findings regarding the ineffectiveness of IVCCI and corrected carotid flow time in predicting PSH in geriatric patients, highlighting the challenges in extrapolating these indices' predictive value across different patient populations and clinical settings.

The consistent findings across these studies, particularly those in geriatric cohorts, suggest that the unique hemodynamic characteristics of older adults, such as reduced cardiovascular reserve and altered autonomic regulation, may diminish the sensitivity and specificity of ultrasonographic indices like CFTc and IVCCI. In the index study, despite comparable heart rates between groups, subsequent MAP reductions in the PSAH group underscore the complex interplay of age-related cardiovascular changes [27]. This complexity, influenced by multifactorial age-related changes, may not be adequately captured by static or dynamic ultrasonographic measures alone.

Discordant Studies

Conversely, some studies and meta-analyses have reported more optimistic results regarding the predictive value of IVCCI for PSAH, leading to a degree of controversy in the literature.

A recent meta-analysis by Chang et al. [25, 32] investigated the utility of IVCCI in predicting PSAH across 12 studies involving 1076 patients undergoing non-cesarean section (CS) surgeries or CS. This comprehensive analysis revealed that patients experiencing PSAH exhibited significantly higher IVCCI values compared to those without PSAH, with a mean difference of 11.12%. The pooled incidence rate of PSAH was found to be 40.5%, underscoring its clinical relevance. Importantly, IVCCI demonstrated robust diagnostic reliability with a sensitivity of 77% and specificity of 82%, supported by a high pooled AUC of 0.85, indicating its effectiveness in identifying patients at risk of PSAH. Despite these strengths, the study suggested the need for future research to evaluate its applicability in high-risk patient groups and explore strategies to integrate IVCCI into clinical practice to enhance patient safety. The discrepancy between these results and our index study may be attributed to several factors, including the heterogeneity of included studies in the meta-analysis (which encompassed younger adult populations and pregnant women), the varying definitions of hypotension, and physiological differences across patient cohorts. For instance, the physiological changes in pregnant women, including increased blood volume and altered cardiovascular dynamics, may influence IVC behavior differently than in the elderly.

Another study by Sethi et al. [33] focused on evaluating IVCCI as a predictor of hypotension in patients undergoing central neuraxial block (CNB) for elective surgery, a context with limited prior research on IVCCI's perioperative utility. This prospective observational study included 100 ASA grade I/II patients aged 18–60 years. They found that patients with a preoperative IVCCI ≥50% exhibited a significantly higher incidence of hypotension (56.60%) compared to the group with IVCCI <50% (4.87%), demonstrating IVCCI's predictive value ($P < .001$). Moreover, the group with IVCCI ≥50% required more vasopressors and fluid boluses, indicating greater hemodynamic instability. These findings underscore the potential of preoperative IVCCI assessment to guide proactive management strategies aimed at reducing the incidence and severity of hypotension following CNB in elective surgical settings. The stark contrast with our index study can largely be explained by the significant difference in the age of the patient population; Sethi et al. focused on a younger adult cohort (18-60 years), whose cardiovascular and autonomic reserves are typically more robust and react differently to sympathetic blockade than those of geriatric patients.

These discordant findings highlight the critical importance of patient population characteristics when evaluating the predictive accuracy of hemodynamic indices. While IVCCI may demonstrate good predictive value in younger, healthier, or specific physiological states (e.g., pregnancy), its utility appears

to diminish significantly in the elderly due to their complex and often compromised cardiovascular and autonomic regulatory systems.

Clinical Implications and Future Directions

The findings of the index study and several concordant investigations carry significant clinical implications for the management of geriatric patients undergoing spinal anesthesia. The consistent observation that neither corrected carotid flow time (CFTc) nor inferior vena cava collapsibility index (IVCCI) reliably predict post-spinal anesthesia hypotension (PSAH) independently in this vulnerable population suggests that clinicians should exercise caution when relying solely on these ultrasonographic parameters for risk stratification.

Clinical Implications:

1. **Caution in Reliance:** The results indicate that CFTc and IVCCI, despite their theoretical appeal and ease of use, may not provide sufficient discriminatory power to guide proactive interventions for PSAH in geriatric patients. Over-reliance on these single-parameter assessments could lead to a false sense of security or, conversely, unnecessary interventions.

2. **Need for Comprehensive Assessment:** Given the multifactorial nature of hypotension in the elderly and their reduced physiological reserves, a holistic approach to risk assessment remains paramount. This should encompass a thorough clinical history (including comorbidities and medication review), detailed physical examination, and consideration of multiple hemodynamic parameters (e.g., baseline blood pressure, heart rate variability, and potentially more advanced cardiac function assessments where indicated).

3. **Proactive Management:** As PSAH remains common and impactful in geriatrics, proactive strategies, such as judicious fluid administration, low-dose vasopressor infusions, or co-loading techniques, should be considered based on a broader clinical picture rather than isolated ultrasonographic readings.

4. **Individualized Care:** The heterogeneity of the geriatric population, in terms of physiological reserve and comorbidities, necessitates highly individualized anesthetic plans. What works for one elderly patient may not be suitable for another, even with similar baseline vital signs.

Future Research Directions: To enhance the assessment and management of PSAH risk in geriatric patients, future research should focus on the following areas:

1. **Multicenter Studies with Larger Cohorts:** The single-center design of the index study limits the generalizability of its findings. Future research should involve large, multicenter prospective studies to validate these results across diverse geriatric populations, accounting for variations in comorbidities, physiological reserve, and anesthetic practices.

2. **Integration of Multiple Parameters:** Instead of relying on single indices, future studies should explore the predictive value of combining CFTc and IVCCI with other clinical, physiological, and potentially biochemical parameters. This could include baseline systemic vascular resistance, cardiac output, left ventricular function, autonomic function tests, and inflammatory markers.

3. **Advanced Predictive Models:** The development and validation of advanced predictive models, such as machine learning algorithms, that integrate a wide array of clinical and hemodynamic data could

offer a more robust approach to PSAH risk stratification in the elderly. These models could identify complex patterns and interactions that single-parameter indices might miss.

4. **Dynamic Tests in Geriatrics:** Further research is needed on the utility of dynamic fluid responsiveness tests (e.g., passive leg raise, end-expiratory occlusion test) in conjunction with ultrasonographic indices in the geriatric population. These tests may provide more accurate insights into fluid responsiveness than static measures alone, even in the context of altered compliance.

5. **Personalized Fluid and Vasopressor Strategies:** Research should investigate how comprehensive risk assessment can guide personalized fluid management and vasopressor strategies to optimize hemodynamic stability and minimize complications in elderly patients undergoing spinal anesthesia. This could involve adaptive algorithms that adjust interventions based on real-time hemodynamic responses.

6. **Longitudinal Outcomes:** Studies should extend beyond immediate intraoperative outcomes to assess the long-term impact of PSAH and its prevention on postoperative morbidity (e.g., acute kidney injury, myocardial injury, cognitive dysfunction) and mortality in geriatric patients.

By addressing these research gaps, the medical community can develop more comprehensive and accurate predictive tools for PSAH, ultimately enhancing patient safety and improving outcomes in this vulnerable population.

Conclusion

Post-spinal anesthesia hypotension (PSAH) remains a prevalent and significant concern, particularly in geriatric patients whose diminished physiological reserves heighten their vulnerability to adverse outcomes. This narrative review, informed by a recent prospective observational study and a synthesis of current literature, concludes that ultrasonographic corrected carotid flow time (CFTc) and inferior vena cava collapsibility index (IVCCI) cannot be independently relied upon as accurate predictors of PSAH in elderly individuals. This limitation is largely attributed to the complex age-related alterations in cardiovascular reserve and autonomic regulation that characterize the geriatric population, which may obscure the predictive utility of these singular hemodynamic indices.

While some studies in younger or specific patient cohorts suggest better predictive performance for IVCCI, the consistent findings in geriatric-focused research underscore the need for a nuanced approach. For older adults, a comprehensive, multifactorial risk assessment is imperative, moving beyond isolated ultrasonographic measurements to integrate clinical history, comorbidities, and a broader array of hemodynamic parameters. Future research must prioritize large-scale, multicenter studies, develop advanced predictive models, and investigate personalized management strategies to enhance the safety and optimize the outcomes for geriatric patients undergoing spinal anesthesia. The ultimate goal is to equip clinicians with more robust tools to anticipate and effectively mitigate the risks associated with PSAH in this vulnerable demographic.

References

1. **Hasanin, A., Mokhtar, A. M., Badawy, A. A., & Fouad, R. (2017).** Post-spinal anesthesia hypotension during cesarean delivery, a review article. Egypt J Anaesth.

2. **Van De Velde, M. (2019).** Low-dose spinal anesthesia for cesarean section to prevent spinal-

induced hypotension. Curr Opin Anaesthesiol.

3. **Kähönen, E., Lyytikäinen, L. P., Aatola, H., Koivistoinen, T., Haarala, A., Sipilä, K., ... & Jula, A. (2020).** Systemic vascular resistance predicts the development of hypertension: the cardiovascular risk in young Finns study. Blood Pressure.

4. **Choi, M. H., Chae, J. S., Lee, H. J., & Woo, J. H. (2020).** Pre-anesthesia ultrasonography of the subclavian/infraclavicular axillary vein for predicting hypotension after inducing general anesthesia: A prospective observational study. European Journal of Anaesthesiology.

5. **Mazumder, H., Hossain, M. M., & Das, A. (2020).** Geriatric Care during Public Health Emergencies: Lessons Learned from Novel Corona Virus Disease (COVID-19) Pandemic. Journal of Gerontological Social Work.

6. **Lee, H., Lee, E., & Jang, I. Y. (2020).** Frailty and comprehensive geriatric assessment. J Korean Med Sci.

7. **Sourdet, S., Brechemier, D., Steinmeyer, Z., Gerard, S., & Balardy, L. (2020).** Impact of the comprehensive geriatric assessment on treatment decision in geriatric oncology. BMC Cancer.

8. **Gosch, M., Singler, K., Kwetkat, A., & Heppner, H. J. (2020).** Geriatrics in times of corona. Z Gerontol Geriatr.

9. **El Hayek, S., Cheaito, M. A., Nofal, M., Abdelrahman, D., Adra, A., Al Shamli, S., ... & Ghandour, L. A. (2020).** Geriatric Mental Health and COVID-19: An Eye-Opener to the Situation of the Arab Countries in the Middle East and North Africa Region. American Journal of Geriatric Psychiatry.

10. **Saripella, A., Wasef, S., Nagappa, M., Riazi, S., Englesakis, M., Wong, J., ... & Chan, V. (2021).** Effects of comprehensive geriatric care models on postoperative outcomes in geriatric surgical patients: a systematic review and meta-analysis. BMC Anesthesiology.

11. **Mueller, Y. K., Monod, S., Locatelli, I., Büla, C., Cornuz, J., & Senn, N. (2018).** Performance of a brief geriatric evaluation compared to a comprehensive geriatric assessment for detection of geriatric syndromes in family medicine: A prospective diagnostic study. BMC Geriatrics.

12. **Alghanem, S., Massad, I., Almustafa, M., Al-Shwiat, L., El-Masri, M., Samarah, O., ... & Al-Mashagbah, M. (2020).** Relationship between intra-operative hypotension and post-operative complications in traumatic hip surgery. Indian Journal of Anesthesia, 64(1), 18.

13. **Hasanin, A., Mokhtar, A. M., Badawy, A. A., & Fouad, R. (2017).** Post-spinal anesthesia hypotension during cesarean delivery, a review article. Egypt J Anaesth.

14. **Yu, C., Gu, J., Liao, Z., & Feng, S. (2021).** Prediction of spinal anesthesia-induced hypotension during elective cesarean section: a systematic review of prospective observational studies. International Journal of Obstetric Anesthesia, 47, 103175.

15. **Zhang, J., & Critchley, L. A. H. (2016).** Inferior Vena Cava Ultrasonography before General Anesthesia Can Predict Hypotension after Induction. Anesthesiology, 124(3), 580–589.

16. **Ceruti, S., Anselmi, L., Minotti, B., Franceschini, D., Aguirre, J., Borgeat, A., ... & Borgeat, A. (2018).** Prevention of arterial hypotension after spinal anesthesia using vena cava ultrasound to guide fluid management. British Journal of Anaesthesia.

17. **Chowdhury, S. R., Baidya, D. K., Maitra, S., Singh, A. K., Rewari, V., & Anand, R. K. (2022).** Assessment of role of inferior vena cava collapsibility index and variations in carotid artery peak

systolic velocity in prediction of post-spinal anesthesia hypotension in spontaneously breathing patients: An observational study. Indian Journal of Anesthesia, 66(1), 100.

18. **Ayyanagouda, B., Ajay, B. C., Joshi, C., Hulakund, S. Y., Ganeshnavar, A., & Archana, E. (2020).** Role of ultrasonographic inferior venacaval assessment in averting spinal anesthesia-induced hypotension for hernia and hydrocele surgeries—A prospective randomised controlled study. Indian Journal of Anesthesia.

19. **Elbadry, A., El Dabe, A., & Abu Sabaa, M. A. (2022).** 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. Anesthesiology and Pain Medicine.

20. **Chebl, R. B., Wuhantu, J., Kiblawi, S., Dagher, G. A., Zgheib, H., Bachir, R., ... & Bachir, R. (2019).** Corrected carotid flow time and passive leg raise as a measure of volume status. The American Journal of Emergency Medicine, 37(8), 1460–1465.

21. **Hasanin, A., Amin, S., Refaat, S., Habib, S., Zayed, M., Abdelwahab, Y., ... & Abdelwahab, Y. (2019).** Norepinephrine versus phenylephrine infusion for prophylaxis against post-spinal anesthesia hypotension during elective caesarean delivery: A randomised controlled trial. Anesthesia Critical Care and Pain Medicine.

22. **KlÖhr, S., Roth, R., Hofmann, T., Rossaint, R., & Heesen, M. (2010).** Definitions of hypotension after spinal anesthesia for caesarean section: Literature search and application to parturients. Acta Anaesthesiologica Scandinavica.

23. **Wei, H., Tu, H. K., Yao, S. L., & Wu, X. (2021).** Regional tissue oxygen saturation as a predictor of post-spinal anesthesia hypotension for cesarean delivery. Chinese Medical Journal.

24. **Jaremko, I., Mačiulienė, A., Gelmanas, A., Baranauskas, T., Tamošiūnas, R., Smailys, A., ... & Smailys, A. (2019).** Can the inferior vena cava collapsibility index be useful in predicting hypotension during spinal anesthesia in a spontaneously breathing patient? A mini fluid challenge. Acta Medica Lituanica, 26(1), 1–7.

25. **Chang, Y.-J., Liu, C.-C., Huang, Y.-T., Wu, J.-Y., Hung, K.-C., Liu, P.-H., ... & Liu, P.-H. (2023).** Assessing the Efficacy of Inferior Vena Cava Collapsibility Index for Predicting Hypotension after Central Neuraxial Block: A Systematic Review and Meta-Analysis. Diagnostics, 13(17), 2819.

26. **Kim, H. J., Cho, A.-R., Lee, H., Kim, H., Kwon, J.-Y., Lee, H.-J., ... & Lee, H.-J. (2022).** Ultrasonographic Carotid Artery Flow Measurements as Predictors of Spinal Anesthesia-Induced Hypotension in Elderly Patients: A Prospective Observational Study. Medical Science Monitor, 28.

27. **Lian, H., Ding, X., Zhang, H., Liu, D., & Wang, X. (2021).** Hemodynamic characteristics and early warnings in very old patients. American Journal of Translational Research, 13(11), 13310–13320.

28. **Kim, H. J., Cho, A.-R., Lee, H., Kim, H., Kwon, J.-Y., Lee, H.-J., ... & Lee, H.-J. (2022).** Ultrasonographic Carotid Artery Flow Measurements as Predictors of Spinal Anesthesia-Induced Hypotension in Elderly Patients: A Prospective Observational Study. Medical Science Monitor, 28.

29. **Wang, J., Li, Y., Su, H., Zhao, J., & Tu, F. (2022).** Carotid artery corrected flow time and respiratory variations of peak blood flow velocity for prediction of hypotension after induction of

general anesthesia in elderly patients. BMC Geriatrics, 22(1), 882.

30. **Singh, Y., Anand, R. K., Gupta, S., Chowdhury, S. R., Maitra, S., Baidya, D. K., ... & Anand, R. K. (2019).** Role of IVC collapsibility index to predict post spinal hypotension in pregnant women undergoing caesarean section. An observational trial. Saudi Journal of Anesthesia, 13(4), 312–317.

31. **Chowdhury, S., Baidya, D., Maitra, S., Singh, A., Rewari, V., & Anand, R. (2022).** Assessment of role of inferior vena cava collapsibility index and variations in carotid artery peak systolic velocity in prediction of post-spinal anesthesia hypotension in spontaneously breathing patients: An observational study. Indian Journal of Anesthesia, 66(1), 100.

32. **Chang, Y.-J., Liu, C.-C., Huang, Y.-T., Wu, J.-Y., Hung, K.-C., Liu, P.-H., ... & Liu, P.-H. (2023).** Assessing the Efficacy of Inferior Vena Cava Collapsibility Index for Predicting Hypotension after Central Neuraxial Block: A Systematic Review and Meta-Analysis. Diagnostics, 13(17), 2819.

33. **Sethi, D., Jadhav, V. L., & Garg, G. (2023).** Role of Inferior Vena Cava Collapsibility Index in the Prediction of Hypotension Associated with Central Neuraxial Block: A Prospective Observational Study. Journal of Ultrasound in Medicine.