

# The use of preoperative inferior vena cava ultrasound to predict anaesthesia-induced hypotension: a systematic review

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## Abstract

Preoperative ultrasound assessment of inferior vena cava (IVC) diameter and the collapsibility index might identify patients with intravascular volume depletion. The purpose of this review was to gather the existing evidence to find out whether preoperative IVC ultrasound (IVCUS) derived parameters can reliably predict hypotension after spinal or general anaesthesia. PubMed was searched to identify research articles that addressed the role of IVC ultrasound in predicting hypotension after spinal and general anaesthesia in adult patients. We included 4 randomized control trials and 17 observational studies in our final review. Among these, 15 studies involved spinal anaesthesia and 6 studies involved general anaesthesia. Heterogeneity with respect to the patient populations under evaluation, definitions used for hypotension after anaesthesia, IVCUS assessment methods, and cut-off values for IVCUS-derived parameters to predict hypotension precluded pooled meta-analysis. The maximum and minimum reported sensitivity of the IVC collapsibility index (IVCCI) for predicting post-spinal hypotension was 84.6% and 58.8% respectively, while the maximum and minimum specificities were 93.1% and 23.5% respectively. For the prediction of hypotension after general anaesthesia induction, the reported ranges of sensitivity and specificity of IVCCI were 86.67% to 45.5% and 94.29% to 77.27%, respectively. Current literature on the predictive role of IVCUS for hypotension after anaesthesia is heterogeneous both in methodology and in results. Standardization of the definition of hypotension under anaesthesia, method of IVCUS assessment, and the cut-offs for IVC diameter and the collapsibility index for prediction of hypotension after anaesthesia are necessary for drawing clinically relevant conclusions.

**Key words:** inferior vena cava, fluid responsiveness, inferior vena cava collapsibility index, inferior vena cava ultrasound, transthoracic echocardiography, spinal anaesthesia, hypotension, ultrasound.

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Intraoperative hypotension after induction or initiation of anaesthesia is a common complication in clinical practice. It has been associated with poor patient outcomes including increased perioperative morbidity and even mortality [1]. Some special patient populations, such as the elderly and pregnant women undergoing caesarean section, are particularly prone to developing significant anaesthesia-induced hypotension (AIH) due to their unique physiological characteristics. Hypotension after induction of general anaesthesia (PIH, post-induction hypotension) or administration of spinal anaesthesia (PSH, post-spinal hypotension) is common and profound in patients with intravas-

cular volume depletion [2]. It may result in nausea, vomiting, aspiration, dizziness, syncope, acute kidney injury and even cardiac dysrhythmias [3].

Preoperative intravascular volume optimization may help avoid hypotension after induction of anaesthesia. On the other hand, excessive intravascular volume loading might result in side effects of volume overload such as pulmonary oedema, congestive cardiac failure, renal dysfunction, and poor surgical outcomes. Hence, it would be of great value for anaesthesiologists to have a reliable tool for assessing intra-vascular volume status that can accurately predict the occurrence of AIH, so that preoperative fluid administration and optimization

can be instituted for only those who will benefit from it.

There is no consensus yet on the optimal method for the assessment of preoperative intravascular volume status and fluid responsiveness [4]. Various non-invasive modalities such as transthoracic echocardiography (TTE), transthoracic bioimpedance, and the passive leg raising test (PLRT) have been investigated as tools for detecting intravascular volume depletion [4, 5]. Ultrasound (US) imaging of the inferior vena cava (IVC) is being used as a tool for assessing cardiac preload or intravascular volume status and has gained popularity because of its relative ease of use, feasibility, reproducibility, non-invasive nature, and cost-effectiveness. Respiratory phasic variation of the IVC diameter measured as a percentage decrease of IVC diameter at inspiration taking the expiratory diameter as baseline in a spontaneously breathing patient is known as the IVC collapsibility index (IVCCI). For long, it has been considered a reliable predictor of volume status and fluid responsiveness in critically ill patients until very recently a review questioned its utility [6]. Although several recent studies have assessed the role of IVCUS in predicting either PSH or PIH, there is no systematic review on this topic that summarizes the evidence. Whether IVCUS can be used to predict intraoperative hypotension remains an unanswered question. Therefore, the objective of this systematic review is to assess the role of IVCUS-derived parameters to predict PSH or PIH.

**METHODS**

This systematic review was conducted as per PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, and the protocol for this review was prospectively registered [7]. Institute ethics committee approval was waived and informed consent from patients was not applicable due to the nature of the article.

**Search strategy**

Using a pre-defined search strategy #11 “((Inferior vena cava collapsibility index) OR (Inferior vena cava ultrasound) OR (IVC collapsibility index) OR (IVCCI) OR (Inferior vena cava diameter) OR (IVC variability) OR (IVC distensibility) OR (IVC collapsibility) OR (IVC spontaneous breathing) AND (Hypotension))” a literature search was conducted on the search engine PubMed from inception to 18.06.2022 (3:00 PM), along with a meticulous manual search.

1. Inferior vena cava collapsibility index
2. Inferior vena cava ultrasound
3. IVC collapsibility index
4. IVCCI
5. Inferior vena cava diameter

6. IVC variability
7. IVC distensibility
8. IVC collapsibility
9. IVC spontaneous breathing
10. Hypotension
11. #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 AND #10: (N=276)

**Inclusion criteria**

Observational studies and randomized control trials assessing the role of pre-operative IVCUS-derived parameters and PSH or PIH in adult patients were included in the review.

**Exclusion criteria**

Studies involving paediatric patients, those not published in the English language, and studies of which full texts were unavailable or in pre-proof stage were excluded from the review. No communication was made with the authors for the full text if it was not available.

**Study selection**

Initial screening of title and abstracts of the search results was followed by full-text screening of selected articles by SRC, PKD, and DR. In case of any disagreement regarding the inclusion of an article, the opinion of SM or DKB was sought. The study selection process for this review is depicted in Figure 1. Turconi *et al.* [8] investigated 55 high risk cardiac patients undergoing vascular surgery under GA and found IVCCI as a poor predictor of intraoperative hypotension. Aissaoui *et al.* [9] also found IVCCI > 42% as a poor predictor of hypotension after GA induction in 64 patients aged more than fifty years undergoing

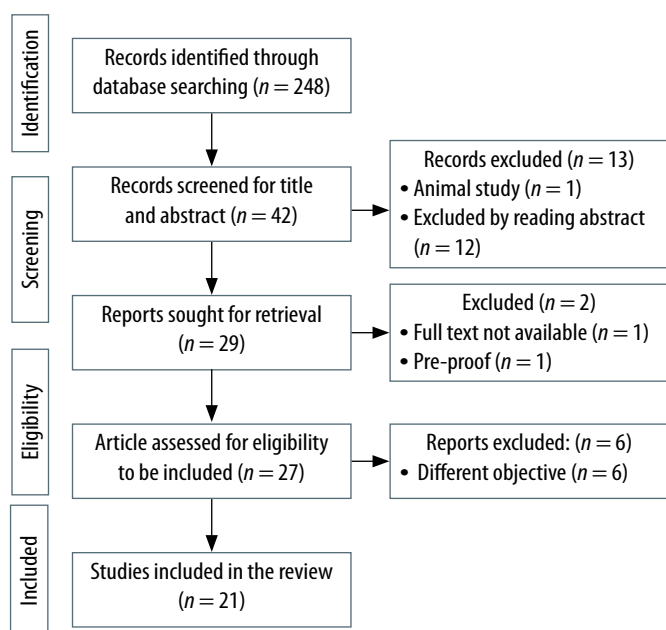


FIGURE 1. Study flow diagram

	Risk of bias				Applicability concerns		
	Patient selection	Index test	Reference standard	Flow and timing	Patient selection	Index test	Reference standard
Aissaoui <i>et al.</i> 2022	+	+	+	+	-	+	+
Aslan <i>et al.</i> 2021	+	+	+	?	+	+	+
Ayyanagouda <i>et al.</i> 2020	+	+	?	-	-	+	+
Ceruti <i>et al.</i> 2018	+	+	+	+	+	+	+
Chowdhury <i>et al.</i> 2022	+	+	+	?	-	+	+
Elbadry <i>et al.</i> 2022	+	+	+	?	+	+	+
Fiza <i>et al.</i> 2020	+	+	+	?	-	+	+
Jaremko <i>et al.</i> 2019	+	+	+	?	-	+	+
Au <i>et al.</i> 2016	+	+	+	+	-	+	+
Kundra <i>et al.</i> 2014	+	+	+	?	+	+	+
Mačiulien'e <i>et al.</i> 2018	+	+	+	?	-	+	+
Ni <i>et al.</i> 2022	+	+	+	+	-	+	+
Devi <i>et al.</i> 2021	+	+	?	-	-	+	+
Purushothaman <i>et al.</i> 2020	+	+	+	?	-	+	+
Roy <i>et al.</i> 2022	+	+	+	?	-	+	+
Mohammed <i>et al.</i> 2021	+	+	+	?	-	+	+
Salama <i>et al.</i> 2019	+	+	+	+	-	+	+
Saranteas <i>et al.</i> 2019	+	+	+	?	+	+	+
Singh <i>et al.</i> 2019	+	+	+	+	+	+	+
Szabo <i>et al.</i> 2019	+	+	+	?	-	?	+
Turconi <i>et al.</i> 2022	+	+	+	+	?	+	+
Yao <i>et al.</i> 2021	+	+	+	?	+	+	+
Zhang <i>et al.</i> 2016	+	+	+	+	-	+	+

- High   
 ? Unclear   
 + Low

**FIGURE 2.** Risk of bias and applicability concerns summary: review authors' judgments about each domain for each included study (green – low risk, yellow – unclear risk, red – high risk)

elective abdominal surgery. These two studies were excluded from our review as the full text of these studies were not available, but wherever applicable we have presented the data available from the abstract of these two studies.

### Data extraction

Relevant data extraction was performed by SRC, SN and DR with respect to the study population, sample size, incidence of PSH or PIH, type of surgery, IVCUS technique, definition of PSH or PIH, drugs used for spinal anaesthesia (SA) or induction of general anaesthesia (GA), IVCCI cut-offs to predict PSH or PIH with sensitivity and specificity, additional parameters derived by IVCUS using the PICO (population, intervention, control, and outcomes) framework.

### Methodological quality of study

#### Risk of bias and applicability concerns summary

Risk of bias at the study level was assessed as per QUADAS 2 methodology and it had four key domains: patient selection; index test; reference standard; flow and timing [10].

#### Effect measures

Primary outcome: Role of pre-operative IVCCI to predict PSH or PIH.

Secondary outcome: Role of other pre-operative IVCUS derived parameters to predict PSH or PIH.

Risk of bias of individual studies was independently assessed by two review authors (SM & DKB) and reported in Figures 2 and 3 (green – low risk, yellow – unclear risk, red – high risk).

Due to extreme heterogeneity of data, sensitivity analysis or meta-analysis was not done.

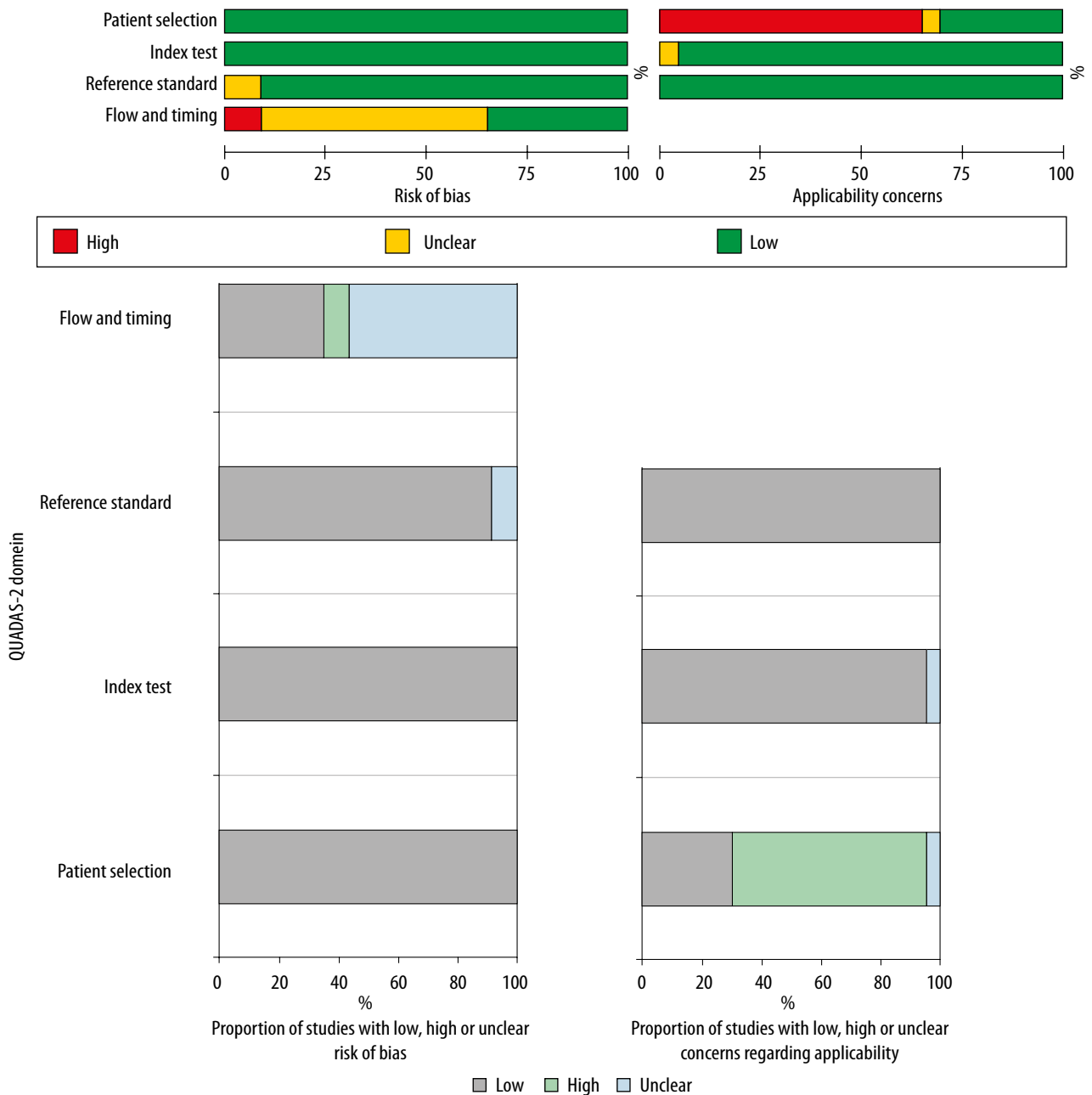
## RESULTS

### Study characteristics

#### Patient population and type of surgery

The role of IVCUS to predict PSH was assessed in 15 studies [11–25]. Among them 4 prospective observational studies evaluated PSH in a parturient undergoing caesarean section [11–14]. The age of the parturient varied between 18 and 40 years.

In studies among non-parturients, 4 studies were randomized controlled trials [15–17, 25] and the rest were observational studies [18–24]. These studies were conducted in procedures such as hernia and hydrocele [16], orthopaedic lower limb surgery [15, 20–22], and various other operations performed under spinal anaesthesia. These studies included adult patients between 18 and 75 years old [19]. Two studies recruited only elderly patients [22, 23]. Among the studies done in non-parturient patients, 8 studies excluded American Society of Anaesthesiology (ASA) class  $\geq$  III [15–21, 24], whereas 1 study each included ASA class I–III [25], ASA class II–III [22] and ASA class I–IV [23] patients.



**FIGURE 3.** Risk of bias and applicability concerns graph: review authors’ judgements about each domain presented as percentages across included studies

Six observational studies evaluated the role of preoperative IVCUS for PIH in non-pregnant patients undergoing elective surgery under GA [26–31]. All these studies were done in adult patients. The ASA class of included patients was I–II in three studies [27, 28, 31], I–III in one study [29], II–III in one study [30], while one study did not mention the ASA class of the patients [26].

**Drugs used**

The local anaesthetic drugs used for SA were both plain and hyperbaric bupivacaine, isobaric ropivacaine and levobupivacaine [11–25]. The most common adjuvant drug for SA was fentanyl. In one study 60 mg of buprenorphine was used [15]. For

GA, 5 studies used propofol [26–28, 30, 31]. One study used etomidate [29]. Fentanyl was co-administered at induction in all but one study [26].

**IVC ultrasound technique**

Low frequency curvilinear [11, 12, 14, 15, 19, 21, 23, 24, 29] or phased array [13, 22, 29] US transducers with the frequency range of 1–8 MHz were used for IVCUS in all these studies. IVC diameter was obtained at a point ranging between 0.5 cm [27] and 5 cm [12] from the IVC-right atrium (RA) junction. In some studies, the IVC diameters were obtained at points ranging between just proximal to [22], to 2 cm distal [20, 21, 30] to the junction of the hepatic vein and IVC.

### Definition of hypotension

The definition of PSH varied widely among different studies: fall in SBP > 20% [11, 13], fall in SBP > 25% [15, 16, 25], fall in SBP > 30% [20], absolute fall in SBP > 50 mmHg [25], SBP value < 90 mmHg [24], SBP < 80 mmHg [25], fall in MAP > 20% [12, 14, 18], fall in MAP > 30% [17, 23], MAP < 65 mmHg [12, 14, 22], MAP < 60 mmHg [15–17, 24, 25], and fall in BP (unspecified) > 30% [19, 21]. The timeframe for PSH was defined as within 15 minutes after spinal drug administration in 3 studies [12, 18, 20], within 30 minutes in 2 studies [19, 23], within 45 minutes in one study [21], and until the end of surgery in two studies [11, 22]. The rest of the studies did not clearly define any timeframe in the definition of PSH.

The definition of PIH also varied widely: SBP < 90 mmHg or use of vasopressors within 21 minutes of propofol administration [26], MAP < 65 mmHg or fall in MAP > 30% [30], MAP < 65 mmHg or fall in MAP > 30% within 10 minutes of propofol administration [28], MAP < 60 mmHg or use of vasopressors until 15 minutes after GA induction [31], SBP < 90 mmHg or fall in SBP  $\geq$  30% [27], and fall in MAP > 30% or MAP < 60 mmHg until 10 minutes of tracheal intubation [29].

### Incidence of hypotension

Incidence of PSH varied from 42.8% [13] to 76% [11] in pregnant patients undergoing caesarean section [11, 13] and from 18.3% to 45% in non-pregnant patients [17, 18, 21]. Incidence of post-induction hypotension varied from 19.3% in the study by Mohammed *et al.* [28] to 70% in the study by Fiza *et al.* [30].

### Predictability of hypotension

IVCCI as a predictor of PSH had the highest sensitivity of 84.6% and the highest specificity of 93.1% in the same study (at a cut-off > 33%) [14]. The lowest sensitivity reported was 58.8% at a cut-off > 21.15% and the lowest specificity was 23.5% at a cut-off > 20.4% [12, 18].

IVCCI as predictor of PIH had the highest sensitivity of 86.67% and the highest specificity of 94.29% in the same study at a cut-off > 43% [31]. The lowest reported sensitivity was 45.5% and the lowest reported specificity was 77.27% both at a cut-off > 50% [26, 27].

Among the parameters other than IVCCI which were obtained from IVCUS, the IVC diameters and IVC peak velocity could not reliably predict PSH in 6 studies [11–13, 18, 20, 21]. However, one study found the minimum IVC diameter to be significantly lower in patients who developed subsequent hypotension [14]. In the study by Aslan *et al.* [23]

the expiratory IVC diameter < 1.8 cm could predict PSH with an odds of 3.289. In another study,  $dIVC_{max}$ -to-IVCCI ratio, where  $dIVC_{max}$  was the maximum diameter of IVC at expiration, was a reliable predictor of PSH in elderly patients aged more than 70 years [22]. The maximum and minimum IVC diameters could not predict PIH in one study [28], but in another study the maximum IVC diameter of < 1.8 cm could predict PIH with moderate sensitivity (73.8%) and specificity (70.8%) [29]. The population characteristics, different definitions of anaesthesia-induced hypotension and the drugs used in different studies are presented in Table 1. Different methods of IVCUS and the important findings of the studies are presented in Table 2. The data collected from the abstract of the two studies which were excluded due to non-availability of the full text are also included in Table 1 and Table 2, as both these studies had the objective of our interest.

## DISCUSSION

In this systematic review, we have come across contrasting results from studies using IVCUS for prediction of AIH. Heterogeneity with respect to the patient populations under evaluation, definitions used for hypotension after anaesthesia, IVCUS assessment methods, and cut-off values for IVCUS-derived parameters to predict hypotension precluded pooled meta-analysis. The maximum and minimum reported sensitivity of the IVCCI for predicting PSH was 84.6% and 58.8% respectively, while the maximum and minimum specificities were 93.1% and 23.5% respectively. For the prediction of hypotension after general anaesthesia (GA) induction, the reported ranges of sensitivity and specificity of IVCCI were 86.67% to 45.5% and 94.29% to 77.27%, respectively.

The cause of this wide disparity in results is multifactorial. Firstly, there is a lack of consensus on the definition of hypotension under anaesthesia. Klöhr *et al.* [32], in an elaborate review of available literature on hypotension under spinal anaesthesia during caesarean section, found at least 15 different definitions of 'hypotension' in the 63 publications retrieved. This resulted in a wide range of the incidence of PSH from 7.4% to 74.1%. The authors reported that even minor changes of the definition cause major differences in the observed incidence of hypotension. This makes comparison between studies difficult and pooling of results nearly impossible.

The present review found 11 different definitions for PSH and 6 for PIH. The timeframe for defining PSH also varied widely, from within 15 minutes of the spinal injection to until the end of surgery. During operations under SA, the most vulnerable period for hypotension is the initial few minutes fol-

TABLE 1. Population characteristics, definition of anaesthesia-induced hypotension and drugs used in included studies

S. no	Author and year	Study type, sample size	Population	Definition of intraoperative hypotension	Incidence of hypotension	Drugs used and dosage	
Spinal anaesthesia	Pregnant patients	1	Yao <i>et al.</i> , 2021 [13] Observational 56	Age 18–40 years parturient undergoing caesarean section	Fall in SBP > 20% from the baseline	42.8%	0.75% isobaric ropivacaine (12 mg) with fentanyl (10 mg) in spinal; 27-G Whitacre needle
		2	Kundra <i>et al.</i> , 2014 [11] Observational 32	Age 20–30 years parturient undergoing caesarean section	Fall in SBP > 20% by the end of surgery	76.0%	9 mg (0.5%) bupivacaine in spinal
		3	Singh <i>et al.</i> , 2019 [12] Observational 40	Parturient undergoing caesarean section	20% fall in MAP or MAP < 65 mmHg within 15 minutes	57.5%	8 mg (0.5%) heavy bupivacaine with 20 mg fentanyl in spinal; 25G Sprotte needle
		4	Elbadry <i>et al.</i> , 2021 [14] Observational 55	25–35 years parturient undergoing caesarean section	Fall in MAP > 20% from baseline or MAP < 65 mmHg	47.3%	12.5 mg heavy bupivacaine with 20 mg fentanyl; 25G spinal needle
		5	Devi <i>et al.</i> , 2021 [15] RCT 100	18–60 years old, ASA class I–II patients undergoing orthopaedic lower limb surgery; one group received IVCUS guided fluid therapy (CI) and the other group did not undergo IVCUS (NCI)	25% fall from baseline SBP or MAP < 60 mm Hg	28.0% overall; 18.0% in CI group and 38.0% in NCI group	12–15 mg heavy bupivacaine with 60 mg (0.2 mL) buprenorphine in spinal; 25G Quincke's needle
	Non-pregnant patients	6	Ayyanagouda <i>et al.</i> , 2020 [16] RCT 80	18–60 years, ASA class I–II patients undergoing inguinal hernia and hydrocele surgery. Randomised to two groups – IVCUS guided fluid therapy (group A) and no IVCUS (group B)	25% fall in baseline SBP or MAP < 60 mm Hg	35.0% in Group A, 20.0% in group B	15–18 mg 0.5% heavy bupivacaine; 25G Quincke's needle
		7	Ceruti <i>et al.</i> , 2018 [25] RCT 160	18–65 year, ASA class I–III patients non-cardiac, non-obstetric surgery under spinal anaesthesia; one group received IVCUS guided fluid therapy (group IVCUS) and the other group did not undergo IVCUS (group C)	Fall in SBP > 50 mmHg or 25% of baseline, absolute SBP < 80 mmHg, MAP < 60mmHg, 30% fall in MAP for more than 30 seconds	35.0% overall, 27.5% in IVCUS and 42.5% in other group	12–18 mg (0.5%) heavy bupivacaine with 27G pencil point spinal needle
		8	Ni <i>et al.</i> , 2022 [17] RCT 90	18–65 years, ASA class I–II patients undergoing non-cardiovascular, non-obstetric surgery under spinal anaesthesia. Randomized to two groups – IVCUS guided fluid therapy (IVCCI group) and standard fluid therapy without IVCUS (Standard group)	Fall in MAP > 20% within 15 minutes after spinal anaesthesia	23.8%; 31.7% in standard group and 15.3% in IVCCUS group	12–15 mg 0.5% plain bupivacaine; 25G Quincke needle
		9	Chowdhury <i>et al.</i> , 2022 [18] Observational 50	Age 18–65 years, ASA class I–II patients undergoing elective infra-umbilical surgery	30% fall from baseline BP (not clearly mentioned SBP/DBP/MAP) till 30 minutes	34.0%	12.5 mg 0.5% heavy bupivacaine with 25 mg fentanyl in spinal
		10	Roy <i>et al.</i> , 2021 [19] Observational 129	Age 18–75 years, ASA I–II patients undergoing elective surgery under spinal anaesthesia	Fall in SBP > 30% from baseline measured until 15 minutes after spinal anaesthesia	19.4%	12.5–15 mg 0.5% heavy bupivacaine in spinal; 25 or 27G Quincke's needle

TABLE 1. Cont.

S. no	Author and year	Study type, sample size	Population	Definition of intraoperative hypotension	Incidence of hypotension	Drugs used and dosage
11	Jaremko <i>et al.</i> , 2019 [20]	Observational 60	Age > 18 years, ASA class I–II patients undergoing knee joint replacement surgery	Fall in SBP more than or equal to 25% or MAP < 65 mmHg for 30 seconds until the end of surgery	18.3%	15–17 mg levobupivacaine in spinal
12	Saranteas <i>et al.</i> , 2019 [22]	Observational 70	Elderly patients > 70 years; ASA class II–III, undergoing lower limb surgery under spinal anaesthesia	Fall in MAP > 30% from baseline within 30 minutes after spinal anaesthesia	41.0%	12–18 mg 0.75% plain ropivacaine in spinal; 22 or 25 G pencil point spinal needle; additionally to facilitate lateral positioning for spinal anaesthesia US guided PNBs were performed; 10–20 mg propofol administered before PNBs
13	Aslan <i>et al.</i> , 2021 [23]	Observational 73	Age > 65 years, ASA I–IV patients undergoing surgery under spinal anaesthesia	Fall in BP > 30% from baseline (SBP/DBP/MAP not mentioned) measured for 45 minutes	38.4%	12.5 mg 0.5% bupivacaine; 25G Quincke needle
14	Mačuliėnė <i>et al.</i> , 2018 [21]	Observational 60	Age ≥ 18 years, ASA class I–II patients undergoing knee joint replacement surgery	Fall in MAP > 30% of the baseline value or any MAP < 60 mmHg; severe hypotension defined as MAP < 55 mm Hg	18.3%	15–17 mg levobupivacaine in spinal; 27-G spinal pencil type needle
15	Salama <i>et al.</i> , 2019 [24]	Observational 100	Age > 18 years, ASA class I–II patients undergoing elective surgery under spinal anaesthesia	SBP < 90 mmHg or fall in SBP > 30% of the baseline value or any MAP < 60 mmHg	45.0%	12 to 15 mg 0.5% hyperbaric bupivacaine in spinal; 26-gauge Whitacre needle
16	Turconi <i>et al.</i> , 2022 [8] (only abstract available)**	Observational 55	High risk cardiac patients undergoing vascular surgery under general anaesthesia	Three definitions of intraoperative hypotension were used: systolic blood pressure (SBP) less than 100 mmHg, mean arterial pressure (MAP) less than 60 mmHg, and a decrease in MAP greater than or equal to 30% compared to baseline	NA	NA
17	Aissaoui <i>et al.</i> , 2022 [9] (pre-proof, only abstract available)**	Observational 64	Age > 50 years; patients undergoing elective abdominal surgery under GA	SBP < 90 mmHg or MAP < 65 mmHg or fall in MAP > 30% from pre-induction level	51.0%	NA
18	Au <i>et al.</i> , 2016 [26]	Observational 40	Age > 18 years, patients undergoing elective surgical procedures under general anaesthesia	SBP < 90 mm Hg or use of vasopressors within 21 minutes after administration of propofol	45.0%	Propofol dose at the discretion of the anaesthesiologist; mean dose: 2.4 mg kg <sup>-1</sup> ; no mention of fentanyl or MR



TABLE 1. Cont.

S. no	Author and year	Study type, sample size	Population	Definition of intraoperative hypotension	Incidence of hypotension	Drugs used and dosage
19	Fiza <i>et al.</i> , 2020 [30]	Observational 63	Adult patients, ASA class II–III undergoing non-cardiac surgery under GA	MAP < 65 mmHg or fall in MAP > 30% from preoperative value	70.0% according to definition by MAP < 65 mmHg, 68.0% according to fall in MAP, 49.0% for both definitions	Mean (SD) propofol dose 1.86 mg kg <sup>-1</sup> (0.34 mg kg <sup>-1</sup> ) with mean fentanyl 125 mg at general anaesthesia induction; 93.7% patients received fentanyl; 73% patients received midazolam 1–2 mg before induction; no mention of MR
20	Punushothaman <i>et al.</i> , 2020 [31]	Observational 50	Age > 18 years, ASA classes I and II patients undergoing surgery under general anaesthesia with propofol as induction agent	MAP < 60 mmHg or use of rescue vasopressors till 15 minutes after GA induction	30.0%	Midazolam 0.05–0.1 mg kg <sup>-1</sup> , propofol 1–2 mg kg <sup>-1</sup> with fentanyl 2–3 mg kg <sup>-1</sup> , atracurium as muscle relaxant 0.5 mg kg <sup>-1</sup>
21	Mohammed <i>et al.</i> , 2021 [28]	Observational 110	Age 18 to 50 years, ASA class I and II patients undergoing surgery under GA with propofol for induction	MAP < 65 mmHg or fall in MAP > 30% from baseline to 10 minutes from GA induction; significant hypotension MAP < 55 mm Hg or fall in BP > 40% or hypotension duration ≥ 2 min	19.3%	Midazolam, fentanyl, propofol, MRs (not specified) dose at the discretion of anaesthesiologist
22	Szabo <i>et al.</i> , 2019 [27]	Observational 83	Age > 18 years, ASA class I–II patients undergoing elective general surgery under general anaesthesia with propofol induction	SBP < 90 mmHg or ≥ 30% drop of SBP from the baseline	34.1% in patients with IVCCI > 50% and 24.2% in patients with IVCCI < 50%	1.5–2 mg kg <sup>-1</sup> propofol with 1–2 mg kg <sup>-1</sup> fentanyl and rocuronium or cis-atracurium
23	Zhang <i>et al.</i> , 2016 [29]	Observational 90	Adult patients, ASA class I to III patients undergoing elective surgery under general anaesthesia with etomidate for induction	Fall in MAP > 30% from baseline or MAP less than 60 mmHg until 10 minutes after tracheal intubation	46.7%	0.01 mg kg <sup>-1</sup> midazolam, 0.3 mg kg <sup>-1</sup> etomidate with 2–3 mg kg <sup>-1</sup> fentanyl with cis-atracurium or rocuronium

IVCUS – inferior vena cava ultrasound, RCT – randomised control trial, ASA – American Society of Anesthesiologists, SBP – systolic blood pressure, MAP – mean arterial pressure, DBP – diastolic blood pressure, PNB – peripheral nerve block, IVCCI – inferior vena cava collapsibility index



TABLE 2. Method of IVC US and important findings of included studies

S. no	Author and year	Method of IVCUS	Parameters derived by IVCUS	Diagnostic accuracy of IVCCI	AUROC IVCCI	Diagnostic accuracy of other parameters derived from IVC US
1	Yao <i>et al.</i> , 2021 [13]	Cardiac probe (5–1 MHz); subphoid view 2–3 cm from right atrium, anteroposterior diameter and peak velocity of IVC (supine position), IVCCI not seen; measurements taken at end-expiration	AP diameter (maximum and minimum) and peak velocity of IVC	–	NA	AP diameter and peak velocity of IVC failed to predict PSH
2	Kundra <i>et al.</i> , 2014 [11]	3–5-MHz curvilinear probe, checked in 3 different positions – supine, wedged recumbent and left lateral; measurements taken at end-expiration and end-inspiration at all positions	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 13.6% in recumbent with wedge position predicts PSH with a positive predictive value of 86%	NA	End expiratory IVC diameter was not a reliable predictor of PSH
3	Singh <i>et al.</i> , 2019 [12]	Curvilinear 3.5–5 MHz probe, subcostal view, supine position with and without wedge, 3–5 cm distal to RA, just proximal to IVC and hepatic vein junction; measurements taken at end-expiration and end-inspiration at both positions	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 25.64% with 60.9% sensitivity and 35.5% specificity for to predict PSH for supine with wedge position; IVCCI > 20.4% with 69.6% sensitivity and 23.5% specificity for non-wedged position	0.46 (wedged position); 0.38 (without wedge)	Maximum and minimum IVC diameter could not predict PSH
4	Elbady <i>et al.</i> , 2021 [14]	Curvilinear USG probe (1–5 MHz, 21 mm), 3–4 cm away from RA just distal to the hepatic vein; after expiration and inspiration	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 33% can predict PSH with 84.6% sensitivity and 93.1% specificity	0.95	Minimum IVC diameter significantly lower in hypotensive group
5	Devi <i>et al.</i> , 2021 [15]	Curvilinear probe of 2–5 MHz, subcostal view, 2–3 cm from RA; measurements taken at maximum end-expiration and at end-inspiration	IVCCI	No correlation between IVCCI cut-off 40% and PSH	NA	–
6	Ayyanagouda <i>et al.</i> , 2020 [16]	Curvilinear probe 1–8 MHz, subcostal view, 2 cm from RA; measurements taken in spontaneously breathing patients	IVCCI	–	NA	No correlation between IVCCI > 36% and baseline MAP
7	Ceruti <i>et al.</i> , 2018 [25]	3S-RS probe, 4 MHz, subcostal view 4 cm from right atrium; measurements taken in spontaneously breathing patients at inspiration and expiration	IVCCI	Slight correlation ( $r^2 = -0.16$ ) between IVCCI > 36% and reduction of MAP after spinal anaesthesia	NA	–
8	Chowdhury <i>et al.</i> , 2022 [18]	2–5 MHz probe, supine position, 1 cm distal to the joining of hepatic vein and IVC; measurements taken during breathing without deep inhalation at 12–15 breaths per minute	IVC diameters (maximum and minimum), IVCmax/IVCCI	IVCCI > 21.15% predicts PSH with 58.8% sensitivity, 69.7% specificity	0.6	No correlation between maximum and minimum IVC diameter and PSH; IVC <sub>max</sub> /IVCCI > 60 predicted PSH with 58.8% sensitivity and 54.5% specificity

Spinal anaesthesia

Pregnant patients

Non-pregnant patients

TABLE 2. Cont.

S. no	Author and year	Method of IVCUS	Parameters derived by IVCUS	Diagnostic accuracy of IVCCI	AUROC IVCCI	Diagnostic accuracy of other parameters derived from IVC US
9	Roy <i>et al.</i> , 2021 [19]	Curvilinear probe 3.5-5 MHz, subxiphoid view, 2-3 cm distal to IVC-RA junction; measurements taken both at expiration and inspiration	IVCCI	Non-significant correlation between IVCCI and PSH ( $r^2 = 0.025$ )	0.467	-
10	Jaremko <i>et al.</i> , 2019 [20]	Probe not mentioned; 1-2 cm below the level of hepatic veins; supine position with one leg bent; measurements taken at breathing rate $16(\pm 2)$ [mean( $\pm$ SD)]	IVC diameters (maximum and minimum) and IVCCI	IVCCI could not predict PSH	< 0.7	Expiratory and inspiratory IVC diameters failed to predict PSH
11	Saranteas <i>et al.</i> , 2019 [22]	2-5 MHz phased array probe, IVC diameters measured just proximal to the entry of hepatic veins; dIVC <sub>max</sub> measured at end-expiration but IVCCI measured at spontaneous quite breathing	IVCCI and dIVC <sub>max</sub> /IVCCI	IVCCI > 30% predicts PSH with 61% sensitivity and 82% specificity	0.77	dIVC <sub>max</sub> /IVCCI < 43 predicts PSH with 80.5% sensitivity and 93% specificity
12	Aslan <i>et al.</i> , 2021 [23]	Curvilinear probe 2-5MHz, subxiphoid view; supine position	IVC diameter (maximum and minimum) and IVCCI	-	0.77 (for end-expiratory diameter)	Expiratory IVC diameter < 1.8 cm can predict PSH with odds of 3.289
13	Mačiulienė <i>et al.</i> , 2018 [20]	Curvilinear 2-6 MHz, subcostal view, 1-2 cm below the level of the hepatic vein, supine position with one leg bent; hypotension and IVCCI were measured at baseline (before SA) and at 4 subsequent time points: 1. Immediately after SA; 2. 15 minutes after SA; 3. 30 minutes after SA; 4. 45 minutes after SA; measurements taken at normal breathing at $14 \pm 2$ min <sup>-1</sup> ; [mean( $\pm$ SD)]	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 50%, does not predict PSH	IVCCI as predictor of hypotension at: 1. Time point-1: AUROC 0.59 2. Time point-2: AUROC 0.57 3. Time point-3: AUROC 0.44 5. Time point-4: AUROC 0.51	Expiratory and inspiratory IVC diameters and IVCCI failed to predict PSH
14	Ni <i>et al.</i> , 2022 [17]	Subcostal view, 2 to 3 cm distal to RA; measurements taken at the end of expiration and inspiration during same respiratory cycle	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 42% can predict PSH with 83.9% sensitivity and 76.3% specificity	0.834 (IVCCI cut-off > 42%)	Patients with smaller IVC diameter developed PSH more frequently
15	Salama <i>et al.</i> , 2019 [24]	Curvilinear 3.5 to 5 MHz probe, subxiphoid view, 3 to 4 cm distal to RA just distal to IVC-hepatic vein junction; measurements taken at the end of expiration and inspiration during same respiratory cycle	IVC diameters (maximum and minimum) and IVCCI	IVCCI > 44.7% can predict PSH with sensitivity of 84%, a specificity of 77% and accuracy of 84%	0.86	-
16	Turconi <i>et al.</i> , 2022 [8] (only abstract available)**	NA		IVCCI poor predictor of intra-operative hypotension	0.62	
17	Aissaoui <i>et al.</i> , 2022 [9] (pre-proof, only abstract available)**	NA		IVCCI > 42% poor predictor of post-induction hypotension	0.68	

TABLE 2. Cont.

S. no	Author and year	Method of IVCUS	Parameters derived by IVCUS	Diagnostic accuracy of IVCCI	AUROC IVCCI	Diagnostic accuracy of other parameters derived from IVC US
18	Au <i>et al.</i> , 2016 [26]	Subxiphoid or intercostal window; 2 cm below entry of hepatic veins into IVC; to avoid off-midline measurements M-mode employed in the transverse plane; measurements taken over one normal respiratory cycle	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 50% predicts post induction hypotension with 66.67% sensitivity and 77.27% specificity	NA	IVCCI ≥ 50% had odds ratio of 6.9 in predicting post induction hypotension
19	Fiza <i>et al.</i> , 2020 [30]	Subcostal view, 2 cm caudal to the hepatic vein-IVC junction; measurements taken at end-expiration and end-inspiration	IVC diameter (maximum and minimum) and IVCCI	Higher IVCCI was associated with increased incidence of PIH for each definition separately with odds of 1.05 for each definition; with both definitions of hypotension taken simultaneously, the IVCCI was not a predictor of hypotension	NA	–
20	Purushothaman <i>et al.</i> , 2020 [31]	Subxiphoid view, 2–3 cm distal to RA; measurements taken in spontaneously breathing patients	IVC diameter (maximum and minimum) and IVCCI	IVCCI of > 43% good predictor of post-induction hypotension with 86.67% sensitivity and 94.29% specificity	0.959	IVCCI > 50% had 53.33% sensitivity and specificity of 100%
21	Mohammed <i>et al.</i> , 2021 [28]	2.5–5 MHz phased array probe, subcostal view, 2–3 cm from RA; readings were taken during a single spontaneous breathing cycle	IVC diameter (maximum and minimum) and IVCCI	IVCCI ≥ 46% had 47 to 59% sensitivity and 48 to 50% specificity for hypotension; 0.46 (significant hypotension)	0.51 (post induction hypotension) dIVC <sub>min</sub> cut-off 0.73 sensitivity 47% to 53% and specificity 50%	dIVC <sub>max</sub> ≥ 1.42 cm sensitivity 47% to 53% and specificity 51 to 53%
22	Szabo <i>et al.</i> , 2019 [27]	5 MHz probe, subxiphoid view, 0.5–3 cm from the RA; if suboptimal view, trans-hepatic lateral view/intercostal view were taken; measurements taken during normal breathing in lightly sedated patients	IVC diameter (maximum and minimum) and IVCCI	IVCCI > 50% had poor sensitivity of 45.5% but high specificity of 90.0% for PIH	0.648	–
23	Zhang <i>et al.</i> , 2016 [29]	Curved linear phased array probe, subcostal view, 2 to 3 cm distal to RA; medium sweep speed kept; measurements taken over single breathing cycle	IVCCI; IVC <sub>max</sub>	IVCCI cut-off 43%, had sensitivity of 78.6% and a specificity of 91.7% for predicting post induction hypotension; IVCCI 38 to 43% considered as grey zone	0.9 grey zone for dIVC <sub>max</sub> 1.5 to 2.1 cm	dIVC <sub>max</sub> cut off 1.8 cm had a sensitivity of 73.8% and specificity of 70.8% for predicting PIH

IVC – inferior vena cava, IVCUS – inferior vena cava ultrasonography, USG – ultrasonography, IVCCI – inferior vena cava collapsibility index, IVC<sub>min</sub> or dIVC<sub>min</sub> – minimum IVC diameter, IVC<sub>max</sub> – maximum IVC diameter, IVC<sub>cut</sub> – area under receiver operator characteristic curve

lowing sub-arachnoid injection of local anaesthetic. Hypotension occurs primarily due to loss of sympathetic tone in the lower half of the body leading to decreased systemic vascular resistance (SVR) due to arteriolar vasodilation, and loss of venous tone leading to reduced mean systemic filling pressure (MSFP) and reduced venous return [33]. As baroreceptor reflex mechanisms gradually restore SVR and blood volume gradually redistributes, venous return is restored, and blood pressure slowly returns toward baseline. Intravenous fluid boluses and short acting vasopressors are usually used to cover this period of sudden hypotension. There is, however, no specific definition for this period in the literature. After 15–30 minutes of spinal injection, the surgical procedure would obviously have started. At this stage, surgical causes such as positioning, retraction and blood loss will confound blood pressure changes. Therefore, until what time PSH can be attributed to sympatholysis by the SA is a matter of conjecture. Similarly, there is hardly any consensus on the definition of PIH in terms of magnitude or timeframe, in patients undergoing GA. Another important aspect of defining PSH or PIH is what should be considered the baseline value. It is very often observed that even normotensive patients, when wheeled into the operating room, have high blood pressure readings, probably because of preoperative stress or anxiety. Whether such blood pressure readings immediately prior to anaesthesia initiation should be considered as baseline or whether the “usual” blood pressure readings obtained during the pre-anaesthesia visit are to be considered remains unclear.

Aside from differences in definition of hypotension, there was remarkable heterogeneity in different aspects of the studies. The study populations in various studies were diverse. IVC dimensions and indices may be different between parturient and non-parturient patients. The IVCUS imaging and measuring techniques used in various studies were different. While a few studies have used a phased-array probe, others have used the curvilinear probe. The exact point at which the IVC diameter was measured in various studies was inconsistent. None of the studies have specified the M-mode sweep speed used during IVC diameter measurement. This may have affected the number of respiratory cycles sampled for measuring minimum and maximum IVC diameter.

The change in IVC diameter with phases of respiration depends not only on intra-vascular volume but also on the depth of respiration [34, 35]. The deeper the inspiratory effort is, the greater is the fall in intrathoracic pressure and consequent collapse of the IVC. Multiple factors including anxiety, pain, and metabolic acidosis may influence the respiratory efforts in an awake patient and can cause sig-

nificant variations in the IVC diameter. It is difficult to standardize or quantify the respiratory efforts in a spontaneously breathing patient. Out of the 23 studies screened in this review, 5 have mentioned that measurement was performed during normal quiet breathing. Others however do not specify the breathing pattern during IVCUS. Studies that have reported a correlation between the attenuation of IVC collapsibility and elevated central venous pressure recommend that patients be asked to take a sudden sharp inspiratory effort, also described as a “sniff” test, during inspiratory IVC diameter measurement [36,37]. It is hypothesized that the sniff manoeuvre can standardize the inspiratory effort and, due to its brief nature, can be performed effectively with ease by both normal and dyspnoeic patients. Whether such a manoeuvre was performed in any of the studies in the present review is not clear.

IVC diameter and phasic variability with respiration have been shown to increase with age [38]. Thus, age too can be a confounding factor when comparing studies on IVC indices.

The heterogeneity in the above discussed factors was probably responsible for the conflicting results reported in the studies in this review. Consequently, a very wide range of individual cut-offs, sensitivities and specificities have been reported, making pooled analysis impossible. Hence, we have not proceeded further with a meta-analysis of the data.

In a meta-analysis of studies predicting fluid responsiveness in critically ill patients using the caval index, Orso *et al.* [6] reported a pooled sensitivity and specificity of 0.71 and 0.75 respectively. However, they pooled data from various studies using different cut-offs, and therefore did not recommend a clear cut-off for the caval index that can accurately predict fluid responsiveness.

The major limitation in our systematic review is that we could not perform a meta-analysis as we did not find enough studies taking the same cut-off values of IVCCI. That has precluded any comparison between age groups or between the pregnant and non-pregnant population, to find out whether IVCUS is useful in a specific subgroup of patients.

In conclusion, the results of studies assessing the utility of IVCCI for predicting AIH are very inconsistent with respect to both the ideal cut-off and diagnostic accuracy. IVCCI may be a simple, safe, and useful tool for predicting PSH and PIH. However, as IVC diameter and collapsibility are dependent on the interplay of multiple additional physiological factors such as intra-thoracic pressure, intra-abdominal pressure and venous compliance, a fixed cut-off may not always be reflective of the intravascular volume status. Hence, IVCUS derived parameters should be used in the appropriate clinical context

to predict AIH. High-quality studies are needed with standardized methodology in terms of age group, patient population, IVCS techniques and definition of hypotension before clear recommendations can be made.

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## REFERENCES

1. Monk TG, Bronsart MR, Henderson WG, et al. Association between intraoperative hypotension and hypertension and 30-day postoperative mortality in noncardiac surgery. *Anesthesiology* 2015; 123: 307-319. doi: 10.1097/ALN.0000000000000756.
2. Kouz K, Hoppe P, Briesenick L, Saugel B. Intraoperative hypotension: pathophysiology, clinical relevance, and therapeutic approaches. *Indian J Anaesth* 2020; 64: 90-96. doi: 10.4103/ija.IJA\_939\_19.
3. Sanborn KV, Castro J, Kuroda M, Thys DM. Detection of intraoperative incidents by electronic scanning of computerized anesthesia records: comparison with voluntary reporting. *Anesthesiology* 1996; 85: 977-987. doi: 10.1097/0000542-199611000-00004.
4. Osman D, Ridell C, Ray P, et al. Cardiac filling pressures are not appropriate to predict hemodynamic response to volume challenge. *Crit Care Med* 2007; 35: 64-68. doi: 10.1097/01.CCM.0000249851.94101.4F.
5. Donati A, Mercuri G, Iuorio S, et al. Haemodynamic modifications after unilateral subarachnoid anaesthesia evaluated with transthoracic echocardiography. *Minerva Anestesiol* 2005; 71: 75-81.
6. Orso D, Paoli I, Piani T, Cilenti FL, Cristiani L, Guglielmo N. Accuracy of ultrasonographic measurements of inferior vena cava to determine fluid responsiveness: a systematic review and meta-analysis. *J Intensive Care Med* 2020; 35: 354-363. doi: 10.1177/0885066617752308.
7. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Ann Intern Med* 2009; 151: 264-269. doi: 10.7326/0003-4819-151-4-200908180-00135.
8. Turconi L, Cavalleri F, Moreno LG, et al. Inferior vena cava ultrasonography before general anaesthesia cannot predict arterial hypotension in patients undergoing vascular surgery. *Rev Esp Anestesiol Reanim (Engl Ed)* 2022; 69: 195-202. doi: 10.1016/j.redare.2021.03.013.
9. Aissaoui Y, Jozwiak M, Bahi M, et al. Prediction of post-induction hypotension by point-of-care echocardiography: a prospective observational study. *Anaesth Crit Care Pain Med* 2022; 41: 101090. doi: 10.1016/j.jccpm.2022.101090.
10. Whiting PF, Rutjes AW, Westwood ME, et al.; QUADAS-2 Group. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011; 155: 529-536. doi: 10.7326/0003-4819-155-8-201110180-00009.
11. Kundra P, Arunsekar G, Vasudevan A, Vinayagam S, Habeebullah S, Ramesh A. Effect of postural changes on inferior vena cava dimensions and its influence on haemodynamics during caesarean section under spinal anaesthesia. *J Obstet Gynaecol* 2015; 35: 667-671. doi: 10.3109/01443615.2014.991291.
12. Singh Y, Anand RK, Gupta S, 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: 312-317. doi: 10.4103/sja.SJA\_27\_19.
13. Yao SF, Zhao YH, Zheng J, Qian JY, Zhang C, Xu Z, Xu T. The transverse diameter of right common femoral vein by ultrasound in the supine position for predicting post-spinal hypotension during caesarean delivery. *BMC Anesthesiol* 2021; 21: 22. doi: 10.1186/s12871-021-01242-8.
14. Elbadry AA. 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: e121648. doi: 10.5812/aapm.121648.
15. Devi KP, Doddamane KP, Manjunath HG, Murdeshwar GN. Use of inferior venacaval collapsibility index in spinal anaesthesia during orthopedic surgeries. *Anesth Essays Res* 2021; 15: 202-207. doi: 10.4103/aer.aer\_108\_21.
16. Basavaraja Ayyanagouda BC, Joshi C, Hulakund SY, Ganeshnavar A, Archana E. Role of ultrasonographic inferior venacaval assessment in averting spinal anaesthesia-induced hypotension for hernia and hydrocele surgeries – a prospective randomised controlled study. *Indian J Anaesth* 2020; 64: 849-854. doi: 10.4103/ija.IJA\_244\_20.
17. Ni TT, Zhou ZF, He B, Zhou QH. Inferior vena cava collapsibility index can predict hypotension and guide fluid management after spinal anaesthesia. *Front Surg* 2022; 9: 831539. doi: 10.3389/fsurg.2022.831539.
18. 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: 100-106. doi: 10.4103/ija.ija\_828\_21.
19. Roy S, Kothari N, Goyal S, et al. Preoperative assessment of inferior vena cava collapsibility index by ultrasound is not a reliable predictor of post-spinal anaesthesia hypotension. *Braz J Anesthesiol* 2022; S0104-0014(22)00051-3. doi: 10.1016/j.bjane.2022.04.001.
20. Jaremko I, Mačiulienė A, Gelmanas A, et al. Can the inferior vena cava collapsibility index be useful in predicting hypotension during spinal anaesthesia in a spontaneously breathing patient? A mini fluid challenge. *Acta Med Litu* 2019; 26: 1-7. doi: 10.6001/actamedica.v26i1.3948.
21. Mačiulienė A, Gelmanas A, Jaremko I, Tamošiūnas R, Smailys A, Macas A. Measurements of inferior vena cava diameter for prediction of hypotension and bradycardia during spinal anaesthesia in spontaneously breathing patients during elective knee joint replacement surgery. *Medicina* 2018; 54: 49. doi: 10.3390/medicina54030049.
22. Saranteas T, Spiliotiaki H, Koliantzaki I, 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: 2421-2427. doi: 10.1053/j.jvca.2019.02.032.
23. Aslan Y, Arslan G, Saraçoğlu KT, Eler Çevik 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: e14622. doi: 10.1111/ijcp.14622.
24. Salama ER, Elakashlan 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: 297-302. doi: 10.1097/EJA.0000000000000956.
25. Ceruti S, Anselmi L, Minotti B, et al. Prevention of arterial hypotension after spinal anaesthesia using vena cava ultrasound to guide fluid management. *Br J Anaesth* 2018; 120: 101-108. doi: 10.1016/j.bja.2017.08.001.
26. Au AK, Steinberg D, Thom C, et al. Ultrasound measurement of inferior vena cava collapse predicts propofol-induced hypotension. *Am J Emerg Med* 2016; 34: 1125-1128. doi: 10.1016/j.ajem.2016.03.058.
27. Szabó M, Bozó A, Darvas K, Horváth A, Iványi ZD. Role of inferior vena cava collapsibility index in the prediction of hypotension associated with general anaesthesia: an observational study. *BMC Anesthesiol* 2019; 19: 139. doi: 10.1186/s12871-019-0809-4.
28. Mohammed S, Syal R, Bhatia P, Chhabra S, Chouhan RS, Kamal M. Prediction of post-induction hypotension in young adults using ultrasound-derived inferior vena cava parameters: An observational study. *Indian J Anaesth* 2021; 65: 731-737. doi: 10.4103/ija.IJA\_1514\_20.
29. Zhang J, Critchley LA. Inferior vena cava ultrasonography before general anaesthesia can predict hypotension after induction. *Anesthesiology* 2016; 124: 580-589. doi: 10.1097/ALN.0000000000001002.
30. Fiza B, Duggal N, McMillan CE, Mentz G, Maile MD. Feasibility of anesthesiologist-performed preoperative echocardiography for the prediction of postinduction hypotension: a prospective observational study. *Anesthesiol Res Pract* 2020; 2020: 1375741. doi: 10.1155/2020/1375741.
31. Purushothaman SS, Alex A, Kesavan R, Balakrishnan S, Rajan S, Kumar L. Ultrasound measurement of inferior vena cava collapsibility as a tool to predict propofol-induced hypotension. *Anesth Essays Res* 2020; 14: 199-202. doi: 10.4103/aer.AER\_75\_20.
32. Klöhr S, Roth R, Hofmann T, Rossaint R, Heessen M. Definitions of hypotension after spinal anaesthesia for caesarean section: literature search and application to parturients. *Acta Anaesthesiol Scand* 2010; 54: 909-921. doi: 10.1111/j.1399-6576.2010.02239.x.

33. 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.
34. Laborda A, Sierre S, Malvè M, et al. Influence of breathing movements and Valsalva maneuver on vena caval dynamics. *World J Radiol* 2014; 6: 833-839. doi: 10.4329/wjr.v6.i10.833.
35. Kimura BJ, Dalugdugan R, Gilcrease GW 3rd, Phan JN, Showalter BK, Wolfson T. The effect of breathing manner on inferior vena caval diameter. *Eur J Echocardiogr* 2011; 12: 120-123. doi: 10.1093/ejehocardi/jeq157.
36. Erhardt CL. Inferior vena caval syndrome and the sniff test for elevated central venous pressure and its contributing factors. *J Diagn Med Sonogr* 1996; 12: 27-33.
37. Kircher BJ, Himelman RB, Schiller NB. Noninvasive estimation of right atrial pressure from the inspiratory collapse of the inferior vena cava. *Am J Cardiol* 1990; 66: 493-496. doi: 10.1016/0002-9149(90)90711-9.
38. Masugata H, Senda S, Okuyama H, et al. Age-related decrease in inferior vena cava diameter measured with echocardiography. *Tohoku J Exp Med* 2010; 222: 141-147. doi: 10.1620/tjem.222.141.