



# Intraoperative Monitoring of the Obese Patient Undergoing Surgery: A Narrative Review

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## ABSTRACT

With the increasing prevalence of obesity in the population, anaesthetists must confidently manage both the pathophysiological and technical challenges presented in bariatric and non-bariatric surgery. The intraoperative period represents an important opportunity to optimise and mitigate risk. However, there is little formal guidance on what intraoperative monitoring techniques should be used in this population. This narrative review collates the existing evidence for intraoperative monitoring devices in the obese patients. Although a number of non-invasive blood pressure monitors have been tested, an invasive arterial line remains the most reliable monitor if accurate, continuous monitoring is required. Goal-directed fluid therapy is recommended by clinical practice guidelines, but the methods tested to assess this had guarded applicability to the obese population. Transcutaneous carbon dioxide (CO<sub>2</sub>) monitoring may offer additional benefit to standard capnography in this population. Individually titrated positive end

expiratory pressure (PEEP) and recruitment manoeuvres improved intraoperative mechanics but yielded no benefit in the immediate postoperative period. Depth of anaesthesia monitoring appears to be beneficial in the perioperative period regarding recovery times and complications. Objective confirmation of reversal of neuromuscular blockade continues to be a central tenet of anaesthesia practice, particularly relevant to this group who have been characterised as an “at risk” extubation group. Where deep neuromuscular blockade is used, continuous neuromuscular blockade is suggested. Both obesity and the intraoperative context represent somewhat unstable search terms, as the clinical implications of the obesity phenotype are not uniform, and the type and urgency of surgery have significant impact on the intraoperative setting. This renders the generation of summary conclusions around what intraoperative monitoring techniques are suitable in this population highly challenging.

**Keywords:** Intraoperative; Monitoring; Obese; Obesity; Perioperative

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### Key Summary Points

With the increasing prevalence of obesity, anaesthetists must be able to confidently manage the associated pathophysiological and technical challenges.

There has been an emphasis on preoperative optimisation and postoperative disposition for this potentially high-risk population.

However, little to date has been published specific to the intraoperative monitoring of this cohort. We summarise the published literature on this topic.

While a range of intraoperative monitoring techniques have been tested, there is guarded applicability of more novel tools (e.g. continuous non-invasive blood pressure monitors) to this population. We currently cannot recommend any changes to standard monitoring practices.

## DIGITAL FEATURES

This article is published with digital features, including a summary slide, to facilitate understanding of the article. To view digital features for this article go to <https://doi.org/10.6084/m9.figshare.14535288>.

## INTRODUCTION

Worldwide, the prevalence of obesity has nearly tripled in the past 40 years [1]. Comorbidities are more frequent in the obese population, including those requiring surgical intervention. It is estimated that approximately 30% of the general surgical population presents with obesity [2]. With an improved safety profile, and evidence to support its long-term efficacy, the volume of bariatric surgery is expected to increase [3]. Meanwhile, the number of obese

patients presenting for non-bariatric surgery continues to grow, demanding expertise of all anaesthetists. Obesity has profound pathophysiological consequences as well as technical challenges of which the anaesthetist must be cognisant. A number of guidelines have been issued which address the perioperative management of the obese patient undergoing surgery [4–7]. A key aspect of these is the drive to facilitate the inclusion of obese patients in ambulatory lists, and enhanced recovery protocols, all of which tend towards minimally invasive strategies for monitoring. These consensus statements have contributed greatly towards the safe management of the patient, with particular focus on the preoperative identification and optimisation of co-morbidities, appropriate equipment in the operating theatre, and a dedicated plan for postoperative disposition. However, while there are published guidelines on the minimum monitoring standards for anaesthesia and recovery [8], there has been little published to date specific to the intraoperative monitoring of the obese patient. This is despite the fact that optimal intraoperative management represents an opportunity for mitigation and avoidance of complications postoperatively. This has been practically realised in terms of, for example, opioid-sparing techniques. The objective of this narrative review is to present and summarise the evidence regarding the intraoperative monitoring of the obese patient.

## METHODS

### Ethics

Our study did not require ethical board approval as it did not contain human or animal trials.

### Identification of Studies/Data Sources

The MEDLINE electronic database via the Ovid Interface was searched using a prespecified search strategy. This was formulated according to the Population, Intervention, Comparison,

Outcome (PICO) criteria, with target population constituting obese patients undergoing surgery and intervention being description of intraoperative monitoring technique [MeSH search terms: obese OR obesity AND intraoperative monitoring]. Additional eligible studies were retrieved by hand searching bibliographies of relevant articles. The search was limited to English language articles only, with date restriction to exclude studies published prior to 2010. The last electronic search was performed on 29 December 2020.

### Study Selection

Article abstracts and subsequently the full text articles were independently assessed for eligibility by two researchers (AH and SN), with any discrepancies referred to corresponding author (PS) for resolution.

The criteria for inclusion were: (1) randomised controlled trials, quasi-experimental and prospective or retrospective observational studies; (2) adults (over 18 years); (3) *obese patients*; (4) examination of intraoperative monitoring technique.

Exclusion criteria were; (1) case reports, case studies, editorials, review articles, and conference abstracts; (2) obstetrics.

### Data Extraction

Two reviewers (AH and SN) extracted data from eligible full-text articles to collate information on study characteristics and outcome measures (Fig. 1).

### Data Synthesis

Anticipated heterogeneity between studies precluded meta-analysis; therefore, the a priori decision to conduct narrative synthesis was taken.

All identified papers were first read and re-read several times with the key points recorded to ensure familiarity with the literature. All included studies were tabulated and translated using content analysis. Relationships in the data were explored using grouping and textual

descriptions. The robustness of the synthesis was evaluated and presented using critical reflection on the synthesis process.

## RESULTS

The majority of studies retrieved concerned the cardiovascular ( $n = 14$ ) [9–22], respiratory ( $n = 7$ ) [23–29], and neurological ( $n = 9$ ) [30–37] systems. Two pertained to point-of-care testing [38, 39]. These were tabulated according to theme (Tables 1, 2, 3, 4, 5, 6, 7, 8, 9, hereafter). The remainder of the studies belonged to miscellaneous systems (renal  $n = 1$  [40], endocrine  $n = 10$  [41]) and are alluded to individually in the discussion. One group reported the results of their enhanced recovery after a bariatric surgery protocol, including specific recommendations around intraoperative monitoring [42].

## DISCUSSION

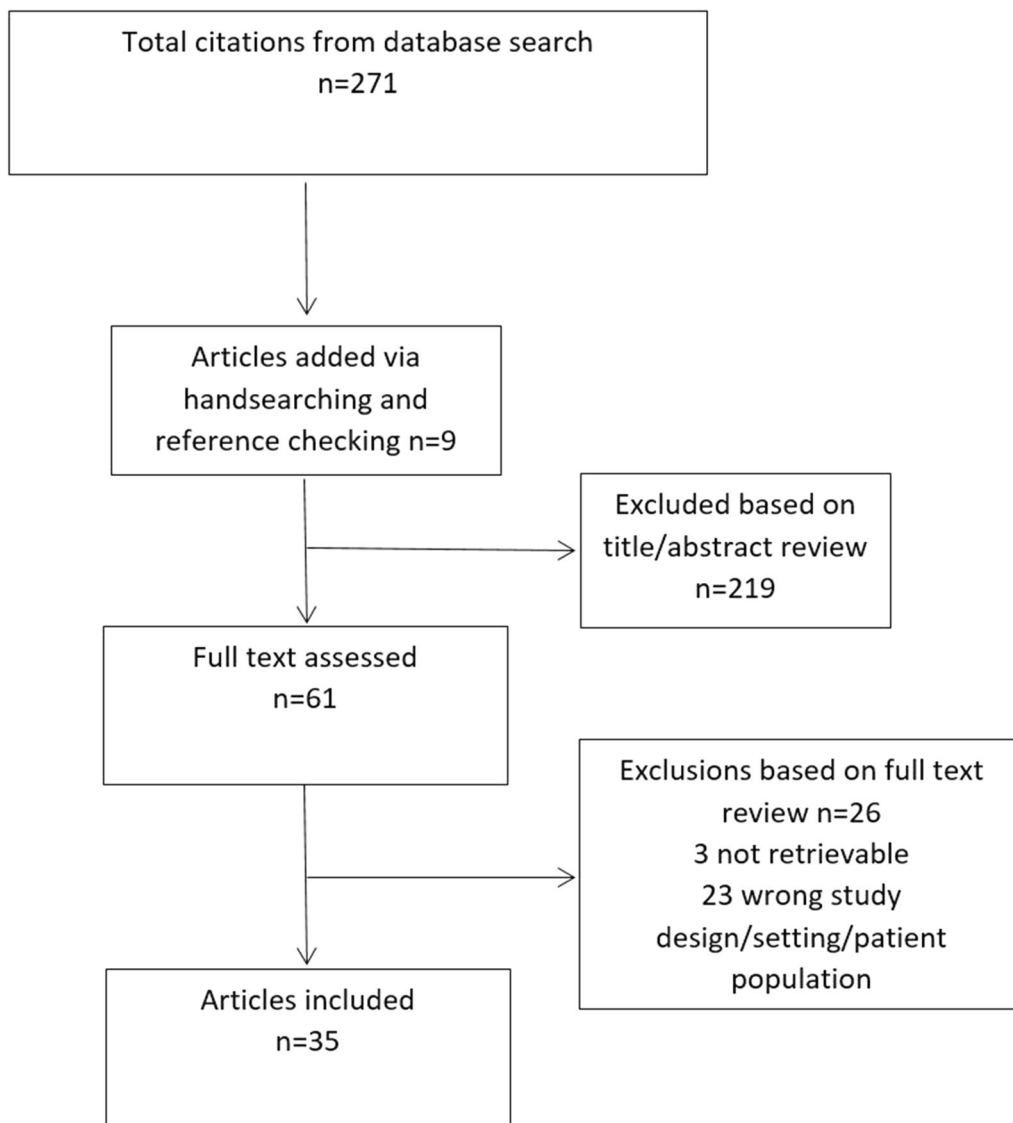
A systems-based approach to reviewing the results was applied, in accordance with the themes which emerged on tabulating the studies.

### Cardiovascular

At a population level, obesity is an established risk factor for cardiovascular disease [43]. The pathophysiological consequences of obesity for the cardiovascular system have been comprehensively elsewhere [44] but include hypertension, atherosclerosis, impaired cardiac function and arrhythmias. Whether these comorbidities directly translate to increased perioperative risk is not clearly established [2, 45]. However, that this is potentially a high-risk population is reflected by the attention to this system in the literature retrieved.

Broadly, there were two themes identified: blood pressure monitoring (Table 1) and cardiac output monitoring (Table 2).

Obese patients are more likely to have hypertension than non-obese. It has also been demonstrated that obesity is a risk factor for inadvertent perioperative hypotension (OR of



**Fig. 1** PRISMA diagram

1.8 for relative hypotension intraoperatively) [46], which itself has been associated with organ damage [47]. A recently published narrative review summarises the difficulties in perioperative blood pressure monitoring in this cohort [48]. The circumference and conical shape of the arm can make non-invasive blood pressure (NIBP) monitoring at the upper arm inaccurate. Longer intervals between NIBP measurements intraoperatively are associated with a four times increased risk of transitioning to hypotension [48]. Continuous measurement may confer more safety in this high-risk cohort.

Traditionally, the mechanism for continuous blood pressure monitoring has been invasive arterial pressure monitoring. Recently, a number of tools for non-invasive continuous measurement have been developed, although the technology was developed and tested in lean patients and has limited evidence base in the obese population [15].

Key considerations are frequency of measurement (intermittent vs. continuous), invasive vs. non-invasive methods, and placement and orientation of blood pressure cuffs.

**Table 1** Blood pressure

Author	Method	Population	Results				Conclusions	
			MD	SDmmHg	LoAmmHg	Concordance coefficient		
Rogge et al Anesthesia/ Analgesia 2018	Prospective simultaneous comparison Test method (continuous non-invasive AP via CNAP) Vs reference method (invasive radial arterial line)	29 patients BMI ≥ 35 Lap bariatric surgery	MAP SAP DAP	± 10.6 ± 16.4 ± 10	- 11.5 to 30.1 - 25.7 to 38.4 - 9.8 to 29.3	97.5% 95% 96.7%	NA NA NA	Good trending capabilities between invasive and CNAP but absolute values not interchangeable and high interpatient variability Technology needs further improvement before it can be recommended for routine clinical use in bariatric surgery
Rogge et al Anesthesia/ Analgesia 2019	Prospective simultaneous comparison Test method (continuous non-invasive AP via Clearight) vs reference method (invasive radial arterial line) Primary outcome was analysis of difference between methods	35 patients Median BMI 47 Lap bariatric surgery	MAP SAP DAP	± 7.4 ± 10.3 ± 6.9	- 13.5 to 15.6 - 14.4 to 27.9 - 12.9 to 14.4	93% (CI 89-96%) 93% (CI 89-97%) 88% (CI 84 - 92%)	NA NA NA	Accuracy and precision good for MAP and DAP, moderate for SAP Good trending capabilities

Table 1 continued

Author	Method	Population	Results			Conclusions		
			MD	SDmmHg	LoAmmHg		Concordance	Correlation coefficient
Greiwe et al BJA 2016	Prospective simultaneous comparison study	28 patients Bariatric surgery	+ 3.97	NA	- 14.47 to 22.41	74% %Error 23.5%	0.75	Note that in 2 patients AT was unable to locate radial artery (while in 1 failure of radial cannulation): difficulty of BP measurement techniques in this cohort
	Test method (applanation tonometry bracclet) vs reference method (invasive radial arterial line)	Mean BMI 49.4 (SD 9.7)	+ 3.45	NA	- 22 to 28.9	72% %Error 23.4%	0.72	
			3.66	NA	- 15.75 to 23.07	71% %Error 30.5	0.65	Authors conclude that technology needs further improvement before recommendation for use in this population

Table 1 continued

Author	Method	Population	Results				Conclusions
			MD	SDmmHg	LoAmmHg	Concordance coefficient	
Anast et al	Prospective simultaneous comparison method	30 patients BMI ≥ 30	MAP 5.2	NA	- 11.2 to 22.2	NA	Based on these results authors cannot recommend a best orientation or placement of non-invasive blood pressure cuff in this population In patients where accurate blood pressure monitoring is necessary, use of invasive monitoring is likely the best approach
Can J Anesth 2015	6 different NIBP measurements (2 at each of upper arm - cuff placed cylindrically, upper arm - cuff placed conically, and forearm vs reference method (invasive radial arterial line))	Non-cardiac surgery	MAP Cylindrical Upper Arm 5.7	NA	- 11.5 to 22.9	NA	
			SAP 5.7	NA	- 18.3 to 24.3	NA	
			DAP 3	NA	- 12.1 to 26.5	NA	
			MAP Conical/ Upper Arm 7.2	NA	- 14.4 to 26-	NA	
			SAP 5.8	NA	- 12.8 to 22.0	NA	
			DAP 4.6	NA	- 14.6 to 20.9	NA	
			MAP Forearm 3.1	NA	- 19.7 to 15.3	NA	
			SAP - 2.2	NA	- 20.7 to 20.9	NA	
			DAP 0.1	NA		NA	

Table 1 continued

Author	Method	Population	Results				Conclusions
			MD	SDmmHg	LoAmmHg	Concordance coefficient	
Schumann et al	Prospective simultaneous comparison study	90 patients	MAP	± 11	- 23 to 21	88%	Note that for 11 patients there were technical difficulties inserting arterial line
Anesthesiology 2020	Test methods × 2 (continuous non-invasive AP via vascular unloading technique ccNexfin/Clearsight© AND oscillometry at upper arm, forearm, lower leg)		Finger				
			SAP	± 14	- 35 to 20	85%	0.85
			DAP	± 11	- 22 to 22	81%	0.81
			MAP	± 15	- 38 to 20	75%	0.57
Vs reference method (invasive radial AP)			Upper arm				Cuff failure occurred in 8 patient at upper arm, 1 at forearm and 11 at lower leg
			SAP	± 18	- 43 to 29	75%	0.6
			DAP	± 15	- 32 to 26	72%	0.5
			MAP	± 13	- 29 to 20	78%	0.67
Forearm			SAP	± 15	- 33 to 26	78%	0.71
			DAP	± 12	- 22 to 26	77%	0.61
			MAP	± 17	- 41 to 25	69%	0.56
			Lower leg				
			SAP	± 22	- 34 to 51	67%	0.52
			DAP	± 18	- 39 to 29	68%	0.43

MD mean difference test versus reference method in mmHg, mmHg millimetres of mercury, SD standard deviation, LoA limits of agreement, BMI body mass index, CNAP continuous noninvasive arterial pressure, AP arterial pressure, MAP mean arterial pressure, SAP systolic arterial pressure, DAP diastolic arterial pressure, AT applanation tonometry, NIBP non-invasive blood pressure, NA not applicable



Table 2 A. Cardiac output

Author, journal, year	Method	Population	Primary outcome	Tool tested	Results	Conclusion
Schraverus et al., Anaesthesia 2016	Comparison of level of agreement and trending ability for CO as measured by Nexfin® vs PiCCO derived values	30 patients Laparoscopic bariatric surgery BMI 44.6 (SD 6.4)	Level of agreement and trending ability for values as measured by two methods	Nexfin® PiCCO 2	Mean (SD) difference 0.6 (1.62) l/min Limits of agreement -2.67 to 3.86 l/min Precision error 46%	Cannot recommend Nexfin® for CO measurement in this population Note that PiCCO has also not been validated in this population
Boly et al J Clin Monitoring 2017	Revisited values of Schraverus et al. to compare at IBW and adjusted BW	30 patients laparoscopic bariatric surgery BMI 44.6 (SD 6.4)	Level of agreement and trending ability at IBW adjusted and actual body weight	As above	IBW Mean (SD) -0.6 (± 1.4) l/min LoA -2.8 to 2.9 l/min Adjusted BW Mean (SD) 0.04 (± 1.4) l/min LoA -2.8 to 2.9 l/min	Improved level of agreement between Nexfin® and PiCCO with adjusted bodyweight suggests directions for improvement for this population
Lorenzen et al. BMC Anesthesiology 2020	Prospective observational study comparing CI measurements derived by Nexfin® vs FloTrac™ at 10 different time points (baseline to end anaesthesia)	54 patients undergoing laparoscopic bariatric surgery BMI 49.2 (± 5.7) kg/m <sup>2</sup>	Level of agreement and interchangeability between CI measurements from test (Nexfin®) vs reference (FloTrac™)	Nexfin® vs FloTrac™	Variable performance/correlation at different time points. Poor correlation at baseline (r = 0.56) and after induction (0.38). Better performance in response to fluid shifts (r = 0.82 after fluid bolus, r = 0.74 with passive leg raise)	Non-invasive (Nexfin®) methods of CI measurement were not interchangeable with semi-invasive (FloTrac™) methods, regarding either absolute or trending values. However, no gold standard invasive reference technique was used
Overall, criterion of interchangeability could not be met, with percentage error 56.51%						

Table 2 continued

Author, journal, year	Method	Population	Primary outcome	Tool tested	Results	Conclusion
Poso et al Obes Surg 2014	Prospective single-centre RCT comparing standard therapy to individualized GDFT (preop TTE and intraop CCOM using Flotrac™)	46 patients laparoscopic bariatric surgery 20 control, 26 intervention	Volume of fluid administered	Flotrac/ Vigileo™	No difference in intraoperative fluid administered between groups. No difference in LoS, complications	Additional invasive monitoring did not affect outcomes
Jain et al Obes Surg 2010	Prospective study to evaluate LidCO© for goal directed therapy: 100 ml crystalloid pm to keep SVV < 10%	50 patients undergoing laparoscopic bariatric surgery BMI mean (SD) 50.39 (± 8.67)	Volume of fluid administered	LidCO©	Mean crystalloid infusion 1989.8 ml (SD ± 468.7) Surgery duration 206.94 min (± 50.3). CVP and SVV correlated during first 2 h, no correlation thereafter	SVV guided optimisation may have a role in guiding fluid administration
Ali et al. Minerva Anestesiologia 2019	Single-centre prospective observation trial to evaluate the effectiveness of minifluid challenge (MFC) in predicting fluid responsiveness in obese patients in the prone position	33 patients undergoing spinal surgery in prone position	Effectiveness of MFC in predicting fluid responsiveness in obese patients prone position	Flotrac/ Vigileo™	MFC AUC 0.967 SVV AUC 0.709 PPV AUC 0.689	MFC was better than SVV or PPV in predicting fluid responsiveness in obese patients in the prone position

Table 2 continued

Author, journal, year	Method	Population	Primary outcome	Tool tested	Results	Conclusion
De Barros et al Obes Surg 2014	Exploratory observational pilot study: BMI $\geq$ 30 undergoing laparoscopic surgery (LO) vs non-obese laparoscopic (LNO) vs open/control(C). Pulse oximeter to measure pleth variability index (PVI) and non-invasive Hb	63 patients in 3 groups (20 LO, 24 LNO, 20 C)	PVI and Hb measured before, during and after abdominal insufflation: values compared between groups, at each timepoint	Massimo radial 7©	Abdominal insufflation significantly affected PVI curves for all laparoscopic surgery but was more pronounced in obese vs non-obese. LO showed sustained elevation of PVI > 15% until time of desufflation	PVI should be used cautiously during laparoscopic procedures, particularly during insufflation
Demirel et al. Obes Surg 2017	RCT - control group (standard fluid regimen: 500 ml bolus plus 4-8 ml/kg/h) vs intervention (500 ml bolus, 2 ml/kg/h plus boluses guided by PVI > 14%)	60 patients undergoing laparoscopic Roux en Y Gastric Bypass Surgery	Volume of fluid administered Lactate levels Creatinine levels	Massimo pulse oximeter	Volume of fluid in control group significantly higher in control group (1499 $\pm$ 516.87 ml) versus intervention (1126 $\pm$ 234.98 ml). No difference in lactate levels or postoperative creatinine	Utilization of GDFT protocols based on PVI may prevent excessive intraoperative infusion of fluids

Table 2 continued

Author, journal, year	Method	Population	Primary outcome	Tool tested	Results	Conclusion
Holzer et al Minerva Anesthesio 2019	Prospective controlled trial to test hypothesis that BMI correlates with fluid during goal-directed therapy and to evaluate subcutaneous tissue oxygen as measure of intravascular volume status and perfusion	90 female patients undergoing open elective gynaec surgery Lean (30) vs overweight (30) vs obese (30)	All 3 groups received intervention (Doppler guided fluid therapy). 75 patients had PsqO <sub>2</sub> assessed	Oesophageal Doppler Subcutaneous tissue oxygen tension (PsqO <sub>2</sub> )	No correlation between BMI and total fluid administered r 0.093 Intraoperative (97.3 vs 86.6 vs 76.9 mmHg) and postoperative (74.5 vs 83 vs 81.5) PsqO <sub>2</sub> no difference between BMI groups	Neither TBW nor BMI should be used to guide fluid infusions. Doppler guided goal-directed therapy was associated with well-maintained subcutaneous tissue oxygenation in all groups

*CO* Cardiac Output, *PiCCO* pulse contour cardiac output, *BMI* body mass index, *SD* standard deviation, *IBW* ideal body weight, *BW* body weight, *CI* cardiac index, *GDFT* goal-directed fluid therapy, *TTE* transthoracic echo, *CCOM* continuous cardiac output monitor, *LoS* length of stay, *SVV* stroke volume variation, *PPV* pulse pressure variation, *CVP* central venous pressure, *MFC* mini fluid challenge, *AUC* area under the curve, *LO* laparoscopic obese, *LNO* laparoscopic non-obese, *PVI* plethysmograph variability index, *Hb* haemoglobin, *TBW* total body weight, *BMI* body mass index, *PsqO<sub>2</sub>* subcutaneous tissue oxygen tension

**Table 3** CO<sub>2</sub> monitoring

Study	Method	Population	Outcome assessed	Results	Conclusion
Soto et al. (2013)	Prospective blinded non randomized study with aim to compare the incidence of hypercapnoea in obese versus non obese patients perioperatively. Secondary aim to compare intraoperative EtCO <sub>2</sub> and TcCO <sub>2</sub>	10 patients BMI > 40 undergoing laparoscopic bariatric surgery and 10 with BMI < 30 undergoing laparoscopic surgery	SenTec™ tcPCO <sub>2</sub> (transcutaneous) monitor	Variable Transcutaneous EtCO <sub>2</sub> Obese n = 9 Mean (SD) mmHg 44.7 (5.7) 33.9 (1.8) Non Obese n = 10 42.6 (4.6) 34.6 (2.8)	p value 0.4 0.51 The difference between EtCO <sub>2</sub> and tcPCO <sub>2</sub> is more pronounced in obese patients than non-obese. Authors conclude that there may be a role for intraoperative transcutaneous CO <sub>2</sub> monitoring in this population
Liu et al. (2014)	To evaluate the accuracy and correlation of estimating PaCO <sub>2</sub> using a transcutaneous monitor	22 patients undergoing laparoscopic bariatric surgery	Arterial, end tidal and transcutaneous CO <sub>2</sub> at various timepoints intraoperatively. Transcutaneous CO <sub>2</sub> measured by TCM-4™ device	Before pneumoperitoneum Variable mmHg PaCO <sub>2</sub> 46.89 ± 2.97 EtCO <sub>2</sub> 38.62 ± 2.69 pTcCO <sub>2</sub> 46.19 ± 3.43 After pneumoperitoneum 30 min mmHg r 50.95 ± 2.59 60 min mmHg r 52.40 ± 2.97 120 min mmHg r 53.73 ± 3.12 0.71 41.33 ± 2.24 0.69 42.14 ± 2.76 0.86 0.93 51.52 ± 3.44 0.90 52.52 ± 3.14 0.90	Transcutaneous CO <sub>2</sub> monitoring provides a better estimate of arterial CO <sub>2</sub> than end tidal CO <sub>2</sub>

EtCO<sub>2</sub> end tidal carbon dioxide, TcCO<sub>2</sub> transcutaneous carbon dioxide, PaCO<sub>2</sub> partial pressure of CO<sub>2</sub>, BMI body mass index, SD standard deviation, mmHg millimetres of mercury

Five studies (Table 1) prospectively and simultaneously compared a reference method (invasive arterial blood pressure monitoring) to a variety of test methods, including continuous non-invasive methods of measurement, and non-invasive blood pressure taken at different sites, and with different cuff orientations.

Continuous non-invasive techniques that were studied included:

1. those based on the volume-clamp method of Penaz, using a finger cuff to measure the change in blood volume of the finger and convert the changes to a continuous waveform using proprietary software [9–11] and
2. those based on applanation tonometry [12], i.e. a sensor bracelet which compresses the radial artery and obtains a continuous arterial pressure signal, processed by an algorithm into a waveform.

While trending capabilities between invasive and non-invasive methods were generally good, the absolute values were not interchangeable, and there was high interpatient variability. The broad conclusion was that this technology needs further refinement and improvement before it can be recommended for use in this cohort, although in the largest comparative study (continuous non-invasive compared to oscillometry at multiple sites and invasive arterial pressure) the finger cuff and invasive methods were comparatively better than the oscillometric versus invasive (concordance 0.75–0.85 vs. 0.43–0.71) [9].

Two studies examined the optimal placement of the blood pressure cuff for non-invasive measurements. In one [9], the forearm performed better than either the upper arm (failed in 15.5%) or lower leg (failed in 39%). However, in the other, the authors [13] were unable to recommend a best orientation or placement of the blood pressure cuff and suggest that in patients where accurate blood pressure monitoring is necessary, use of invasive monitoring is likely the best approach. The limitations of invasive arterial pressure monitoring in this cohort are also demonstrated: difficulty siting an arterial line was reported in 12% of patients in one study [9], indicating the challenges even of the reference standard.

Nine studies considered techniques for monitoring cardiac output intraoperatively, three of which compared two methods of cardiac output monitoring (Table 2a) and six of which considered individualised goal-directed fluid therapy (Table 2b).

Cardiac output monitoring methods can be categorised according to invasiveness (invasive, minimally invasive, and non-invasive) and according to calibration (external calibration vs. uncalibrated methods) [49]. The summary conclusion from the three comparative studies is that there is limited agreement between derived measures of cardiac output and that values were not interchangeable. Overall, there was a guarded applicability of the tested methods to the obese population (albeit a suggestion that inputting adjusted body weight into the algorithm might improve the performance [15]).

Goal-directed fluid therapy (GDFT) is the optimization of tissue perfusion by targeted fluid management. GDFT protocols have been demonstrated to reduce morbidity and length of stay in high-risk surgeries [50]. Excessive perioperative fluid administration has an established adverse effect: the consequence of administration of each extra litre of fluid intraoperatively is an estimated 32% increase in postoperative complications [51]. Meanwhile, a large trial (to which BMI  $\geq 35$  was an inclusion criterion) comparing restrictive (designed to produce net zero fluid balance) to liberal perioperative fluid regimes demonstrated an increased risk of acute kidney injury with restrictive regime [52]. This is of particular concern to the obese surgical patient, in whom the risk of rhabdomyolysis [53] and acute kidney injury [54] is already elevated. Inclusion of non-invasive, dynamic indicators to guide GDFT is suggested for this population [7].

Dynamic indices of fluid responsiveness include respiratory variations in the pulse oximeter (plethysmograph variability indices, PVI) or in the arterial pulse pressure (stroke volume variation [SVV] or pulse pressure variation [PPV]). Six studies (Table 2b) explored the role of goal-directed fluid therapy using diverse expressions of these techniques. The results in this population were somewhat equivocal. In one study, mini fluid challenge was superior to

**Table 4** Intraoperative monitoring of respiratory mechanics

Study	Method	Population	Tool investigated	Results	Conclusions	
Eichler et al. 2017	Prospective comparative study intervention (PEEP titration guided by P <sub>L</sub> ) vs control	37 patients undergoing laparoscopic bariatric surgery	Avea™ Carefusion oesophageal manometer EIT	Intervention n = 20 Target P <sub>L</sub> 0 cmH <sub>2</sub> O  PEEP before capnoperitoneum PEEP after capnoperitoneum  Horowitz index end of surgery Horowitz index at 5 min post extubation  Horowitz index at 60 min post extubation	Control n = 17 PEEP 10 Vt 8 ml/kg IBW 10 cmH <sub>2</sub> O 10 cmH <sub>2</sub> O  340 (± 16.11) 326 (± 24.95)  338.3 (± 17.46)	Elevation of PEEP guided by oesophageal pressure measurement did not lead to improvement in postoperative oxygenation. Significantly greater decrease in Horowitz index noted at 5 min post extubation in intervention group but resolved by 60 min
Nestler et al. BJA 2017	Prospective comparative study intervention (PEEP titration using EIT) vs control (PEEP 5 cmH <sub>2</sub> O)	50 patients BMI ≥ 35 undergoing elective laparoscopic surgery	EIT RVDI	Intervention n = 25 Intubation (SD) PNP (SD)  19.6 (4.7) 28.3 (4.6)  14.6 (4.7) 9.8 (1.4)  43 (13) 61 (13)	Control n = 25 Intubation (SD) PNP (SD)  17.4 (2.7) 22.4 (2.6)  17.4 (2.7) 18.7 (2.6) p < 0.001  12.3 (2.7) 17.4 (2.6) p < 0.001  44 (13) 32 (8)	Individualised PEEP led to improved respiratory system mechanics (see results table) and oxygenation (intervention group had P/F ratio 23 kPa (CI 16–29, p > 0.001) higher than control. However, these differences disappeared in early postoperative period

**Table 4** continued

Study	Method	Population	Tool investigated	Results	Conclusions	
Tusman et al. Anesthesia Analgesia 2014	Prospective: lung recruitment manoeuvre to determine opening and closing pressures lung using pulse ox and volumetric capnography	20 patients undergoing laparoscopic bariatric surgery	Volumetric capnography Lung mechanics Pulse oximeter	Median (IQR) cmH <sub>2</sub> O Opening pressure 44 (4) cmH <sub>2</sub> O Closing pressure 14 (2) cmH <sub>2</sub> O Maintain lungs open 16 (3) cmH <sub>2</sub> O	AUC to detect lung collapse SpO <sub>2</sub> 0.8 VTiCO <sub>2</sub> 0.91 Bohr's 0.83 Pulse oximetry and volumetric capnography can monitor the dynamic changes in the area of gas exchange: induced by recruitment manoeuvres	
Tomescu et al. J Clin Monit Comput 2017	Prospective assessment of ventilatory parameters (standard ventilatory settings Vt 6–8 ml/kg, no PEEP)	50 patients undergoing RAS	Ventilator parameters (plateau, inspiratory hold)	Timeframe Induction Pneumoperitoneum Intraoperative End surgery	BMI 25–30 BMI < 25 Compliance l/cmH <sub>2</sub> O 43.6 45.9 26.1 28.8 32.3 37.8 BMI > 30 p value Combined effect Trendelenburg + BMI p value 0.290 0.360 0.094 0.156	Drop in compliance if > 30% reduced after pneumoperitoneum BMI represents the main risk factor for decreased lung compliance after induction of anaesthesia and insufflation of pneumoperitoneum. Patient positioning did not statistically affect compliance



**Table 4** continued

Study	Method	Population	Tool investigated	Results	Conclusions
Schumann et al. J Clin Anaesth 2016	Prospective validation of accuracy of respiratory impedance monitor by indexing against intraoperative ventilator data	56 patients undergoing bariatric surgery	Non-invasive RVM	Correlation between the ventilator and RVM > 0.95	Clinically relevant accurate performance of non-invasive RVM in morbidly obese population. Authors suggest a role for RVM in monitoring in the postoperative period

*EIT* electrical impedance tomography, *RVDI* Regional Ventilation Delay Index, *P<sub>L</sub>* transpulmonary pressure, *R<sub>AS</sub>* robotic-assisted surgery, *RVM* respiratory volume monitor, *PEEP* positive end expiratory pressure, *IBW* ideal body weight, *V<sub>T</sub>* tidal volume, *VTCO<sub>2</sub>* tidal elimination of carbon dioxide measured by volumetric capnography, *SpO<sub>2</sub>* oxygen saturations, *P/F ratio* arterial partial pressure of oxygen/fraction of inspired oxygen, *kPa* kilopascals, *CI* confidence interval, *SD* standard deviation, *PNP* pneumoperitoneum

e-  
it-

her SVV or PPV in predicting fluid responsiveness (AUC 0.967 vs. 0.709 and 0.689 respectively) [18]. Another found no additional benefit to using semi-invasive cardiac output monitoring regarding intraoperative fluid administered, postoperative complications, or length of stay [16]. Finally, there were conflicting results regarding the non-invasive PVI in this population—while in one study, PVI-guided fluid resulted in a lower volume overall with no detrimental consequences of increases in lactate or postoperative creatinine [21], another showed the unreliability of PVI in laparoscopic procedures [19]. Although endorsed in clinical practice guidelines [7], it is difficult to draw conclusions about the optimal technique to guide fluid administration.

### Respiratory

The respiratory system is a focus of the existing guidelines on perioperative management of the obese patient. Particular emphasis is placed on the identification and preoperative treatment of sleep disordered breathing which confers increased risk at every point of the perioperative pathway, including increased incidence of difficult intubation and increased risk of postoperative pulmonary complications (PPCs).

Respiratory mechanics are significantly altered in obesity and may be further compromised by anaesthesia and surgical access. Increased intra-abdominal pressure combined with decreased total lung capacity, vital capacity, and functional residual capacity lead to atelectasis. Decreased pulmonary compliance intraoperatively, particularly in laparoscopic surgery, leads to higher transthoracic and transpulmonary pressures, increasing the risk of ventilator-induced lung injury. The contribution to surgical mortality attributable to postoperative lung injury is estimated at 19% [55].

PPCs are of particular relevance to the obese population. A subgroup analysis of obese patients recruited within a multicentre international trial found an overall incidence of 10.4% PPCs at postoperative day 5, which increased to 18.5% for Class 3 obesity. PPCs were associated with increased length of

**Table 5** Neuromuscular blockade

Author, journal, year	Method	Population	Primary outcome	Results	Conclusion	
Torensma et al	Double-blind RCT: Deep (0 twitch on TOF, 1–2 on PTC) vs moderate (1–2 on TOF)	100 patients undergoing laparoscopic bariatric surgery	Surgical rating on 5-point Leiden surgical rating scale (1—extremely poor to 5—optimal)	Moderate (n = 50) Deep (n = 50) Rocuronium total dose mg Sugammadex dose mg	Deep NMB improved surgical conditions by 0.7 on a 5-point scale and coupled to lower pain scores in PACU as well as less referred shoulder pain on ward	
PLOS One	TOF-watch-SX monitor		Postop pain scores on PACU and ward	40 (30–130) 70 (45–145) 132 (100–200) 266 (180–370)		
2016				3 (1–6) 3 (1–8)		
Fuchs-Buder et al	RCT: prior to starting gastrojejunal anastomosis, surgical conditions rated. Those with excellent (1) were excluded, the remainder randomised to deep vs moderate	85 patients undergoing laparoscopic bariatric surgery: 20 excluded at first assessment as had excellent (King score 1) surgical conditions	Surgical rating on 4-point King score (1-excellent to 4: unacceptable)	L-SRS Pain score (NRS)	Deep (n = 34) 29 4.8 (4.7–4.9) 3.9 (3.6–4.4)	Deep NMB improved surgical conditions. Poor surgical conditions were associated with more frequent postoperative complications (OR of 7.12, 95% CI 2.16–23.45)
Eur J Anaesth			Perioperative complications	Improvement of surgical conditions Unchanged surgical conditions	4 26	
2019	TOF-watch-SX monitor		Perioperative surgical complications (%)	Worsening of surgical conditions	1 0	
				Patients with King score 4 (unacceptable) 1–3 11 (15.3)	Patients with King score 1–3 11 (15.3)	< 0.0001 < 0.0001

**Table 5** continued

Author, journal, year	Method	Population	Primary outcome	Results	Conclusion
Baete et al., Anaesth-Analg 2017	RCT: assigned to deep NMB (rocuronium bolus plus infusion) or moderate (rocuronium bolus plus top ups), TOF-watch-SX monitor	60 patients undergoing laparoscopic bariatric surgery	Surgical rating on 5-point scale (1: extremely poor to 5: optimal) Postoperative pulmonary complications	<p>Moderate (<math>n = 30</math>) Surgical rating 3.9 (<math>\pm 1.1</math>)</p> <p>Deep (<math>n = 30</math>) 4.2 (<math>\pm 1.0</math>)</p> <p>% Change from Baseline PEF (l/min) 51.5 (<math>\pm 19</math>) 51.3 (<math>\pm 31.6</math>)</p>	No difference in surgically rated operating conditions. Authors proposed that a difference of 2 points on a 5-point scale would be considered significant. Both groups significantly reduced postop pulmonary function

RCT randomised control trial, TOF train of four, PACU post-anaesthetic care unit, L-SRS Leiden Surgical Rating Scale, NMB neuromuscular blockade, OR odds ratio, CI confidence interval, PEF peak expiratory flow

hospital stay [56]. Furthermore, a trial of high PEEP and recruitment manoeuvres vs. low PEEP in almost 2000 obese (BMI  $\geq 35$ ) patients undergoing noncardiac, non-neurological surgery demonstrated an even higher rate of PPCs at day 5, at 21.3% in the intervention and 23.6% in the control group [57].

Broadly, two themes were identified: carbon dioxide (CO<sub>2</sub>) monitoring and quantification of respiratory mechanics.

Two studies (Table 3) looked at the intraoperative use of transcutaneous CO<sub>2</sub> monitors. Capnography has limitations in obese patients because of a greater expired CO<sub>2</sub> to arterial CO<sub>2</sub> gradient than in the non-obese due to increased ventilation/perfusion mismatching [23, 58]. Transcutaneous CO<sub>2</sub> monitors use a variant of the Severinghaus-type CO<sub>2</sub> electrodes, where warmed skin allows CO<sub>2</sub> to diffuse into an electrolyte solution. This has previously been shown to be more accurate in the obese, with a difference of up to 1 kPa between methods [58]. Liu et al. [24] similarly concluded that transcutaneous CO<sub>2</sub> provided a better estimate of arterial CO<sub>2</sub> than end tidal values (correlation coefficient 0.9 versus 0.66 for baseline values).

There may be a role for intraoperative transcutaneous CO<sub>2</sub> monitoring in this cohort in addition to (rather than in place of) capnography. Furthermore (and as was the primary focus of one study [23]), transcutaneous CO<sub>2</sub> monitoring may facilitate safety in the postoperative period.

An increased BMI constitutes the major risk factor for decreased lung compliance during robotic surgery [28]. Adjustment of intraoperative ventilatory parameters has been proposed as a strategy to overcome the adverse respiratory mechanics experienced by the obese patient, particularly undergoing laparoscopic surgery. An excellent narrative review has been published on intraoperative mechanical ventilation strategies, with a focus on specific populations including the obese [56]. We identified several heterogeneous studies which test this approach (Table 4). One study examined the role of volumetric capnography (AUC 0.91) and pulse oximetry (AUC 0.8) in objectively assessing the impact of a recruitment manoeuvre. Notably, a median pressure of 16 cmH<sub>2</sub>O was required to

**Table 6** Depth of anaesthesia monitors

Author	Tool assessed	Design	Primary outcome	Results	AAI	p value	Conclusion	
Freo et al ObesSurg2011	A: line autoregression index (mid-lateny auditory evoked potential, extracted from background EEG activity)	Prospective comparative study standard clinical practice (SCP) vs AAI monitored	Time taken to spontaneous eye opening, obeying commands, extubation. Secondary outcomes included sevo ET and consumption and postop SpO <sub>2</sub>	Variable Time to eye opening To obey command To extubation SpO <sub>2</sub> at arrival in PACU SpO <sub>2</sub> at 10 min SpO <sub>2</sub> at 30 min SpO <sub>2</sub> at 60 min Time to SpO <sub>2</sub> ≥ 92% ET Sevo	SCP 14.8 ± 4.8 16.2 ± 4.4 18.3 ± 5.3 87.0 ± 4.1 87.8 ± 3.5 90.8 ± 1.8 89.6 ± 2.5 34.7 ± 17.0 2.2 ± 0.4 16.7 ± 5.7	AAI 12.4 ± 4.5 13.9 ± 4.9 15.7 ± 5.6 89.1 ± 3.7 90.8 ± 2.9 93.1 ± 1.7 94.2 ± 1.7 17.0 ± 18.5 1.8 ± 0.3 13.3 ± 4.3	0.015 0.071 0.009 0.0005 0.0001 0.0001 0.04 0.001 0.011 0.014	The use of AAI reduced sevoflurane consumption, and recovery times, and did not increase postoperative complaints or recall of intraoperative events
Demirel et al Journal Perianesthesia Nursing 2020	Patient State Index SEDLIne	Prospective double-blind RCT 4 groups: P-PSI (n = 30) TIVA with PSI, P (n = 30) TIVA without PSI, D-PSI (n = 30) desflurane with PSI, D (n = 30) desflurane without PSI	Discharge time from PACU, complications	Variable Recovery time min No PONV (number) Nausea (number) Gagging (number) Vomiting (number)	P 28.73 ± 8.84* 22 4 1 3	D-PSI 31.67 ± 5.91 15 8 2 4	0.002 (P-PSI, P compared with D) 0.01 P-PSI, P and D-PSI compared with D	The use of PSI monitoring intraoperatively may reduce the discharge time from PACU and PONV

**Table 6** continued

Author	Tool assessed	Design	Primary outcome	Results	p value	Conclusion
Ibrahim et al. Anaesthesia Essays and Researches 2013	BIS	RCT with 40 patients—20 in BIS, 20 no BIS	Effect of BIS monitoring on postoperative extubation and recovery times and intraoperative desflurane consumption	Variable Desflurane consumption ml/patient Eye opening to verbal commands (min) Extubation (min) Aldrete score $\geq 9$ (min) Orientation person, time, place (min)	< 0.05 < 0.05 < 0.05 0.16 < 0.05	BIS monitoring improved postoperative recovery and reduced intraoperative desflurane consumption
				Non-BIS n = 20 150.6 $\pm$ 6.5 7.2 $\pm$ 2.1 8.2 $\pm$ 3.1 10.1 $\pm$ 2.5 13.2 $\pm$ 3.3		
				BIS n = 20 124.8 $\pm$ 5.1 5.4 $\pm$ 1.15 6.4 $\pm$ 1.4 9.6 $\pm$ 2.7 10.1 $\pm$ 1.06		

EEG electroencephalogram, AAI A-line autoregression index, SCP standard clinical practice, ET end tidal, SpO<sub>2</sub> oxygen saturation, PACU post-anaesthetic care unit, RCT randomised control trial, PSI patient state index, PONV postoperative nausea and vomiting, BIS bispectral index

keep the lungs “open” [27]. Two studies explored the use of electrical impedance tomography (EIT) to facilitate an individualised titration of PEEP to test the hypothesis that this would offset the atelectasis and consequent decrease in arterial oxygenation that occur in obese patients undergoing general anaesthesia [25, 26]. While both showed an intraoperative improvement in both mechanics and oxygenation, the differences were not sustained into the postoperative oxygenation period.

There is some evidence to suggest that individually titrated PEEP may mitigate the adverse respiratory mechanics at which the obese patient is at higher risk. However, none of the studies demonstrated an improvement into the immediate postoperative period. It is difficult to draw conclusions about the utility of additional intraoperative respiratory monitoring in this population, although in the postoperative period a non-invasive respiratory volume monitor may have a role [29].

### Neuromuscular

Four key themes emerged: neuromuscular blockade monitoring, depth of anaesthesia monitoring, cerebral perfusion, and assessment of pain.

Peripheral nerve stimulators form part of the minimum standards for anaesthetic monitoring, where muscle relaxants have been used [8]. The National Audit Project (NAP) 5 audit into accidental awareness under anaesthesia (AAGA) concluded that the combination of using muscle relaxants, without monitoring their effect, and without reversing them, incurred a risk for AAGA that was roughly 16 times greater when muscle relaxants were used versus none. So strongly was neuromuscular blockade implicated in AAGA that the authors suggest a subtitle of “unintended awareness under neuromuscular block”. Over three times as many obese patients experienced AAGA as non-obese [59]. Furthermore, the incidence of post-operative residual blockade is higher in the obese patient [60]. Consensus guidelines indicate that where muscle relaxants are used in this

**Table 7** Near infrared spectroscopy

Author	Tool assessed	Design	Primary outcome	Results	Conclusion	
Ruzman et al	Near infrared spectroscopy	Prospective, all patients		Induction supine for BMI > 30 Right	$p = 0.045$ Significantly greater declines in rSO <sub>2</sub>	
Surg Laparosc Endos Percut Tech 2017	to measure regional cerebral oxygen saturations (rSO <sub>2</sub> )	undergoing laparoscopic cholecystectomy. Analysed for association between patient characteristics and critical (drop of 20% from baseline value) rSO <sub>2</sub> level		Pneumoperitoneum right for BMI > 30 Pneumoperitoneum left for BMI > 30 Reverse Trendelenburg right for BMI > 30 Reverse Trendelenburg left for BMI > 30	$p = 0.027$ $p = 0.045$ $p = 0.012$ $p = 0.041$	were noted in elderly ( $\geq 65$ years) and obese (BMI $\geq 30$ ) in this cohort during surgery. No association between these factors and baseline rSO <sub>2</sub> . Authors conclude that non-invasive measures of cerebral oxygenation could be helpful in “higher risk” patients including elderly and obese

*NIRS* near-infrared spectroscopy, *rSO<sub>2</sub>* regional cerebral oxygen saturations, *BMI* body mass index

population, neuromuscular blockade should be assessed and reversed prior to extubation [4].

The second aspect to be considered is deep (defined as no twitches on train of four [TOF] or post-tetanic count [PTC] of one or two) versus moderate (two twitches on TOF) blockade. Recent guidelines concluded that there was insufficient data to make recommendations about deep versus moderate blockade for obese patients undergoing laparoscopic surgery [61]. Despite this, deep blockade is, in practice, more commonly used in this population: a retrospective review of 88,000 general anaesthetics in which muscle relaxants were used found that a higher BMI class was the major patient-specific factor associated with deep blockade [62]. Three studies looked at deep versus moderate neuromuscular blockade (Table 5). Two studies found that deep neuromuscular blockade

improved surgeon-reported operator conditions during laparoscopic bariatric surgery, with a consequent reduction in perioperative complications [36] and pain [35]. There was no increase in time to extubation with deep blockade, although dose of reversal was higher. A third study ( $n = 60$ ) [37], found no difference in operating conditions with deep blockade and no difference in length of surgery. A secondary outcome was postoperative pulmonary function tests: both groups demonstrated a marked decline in function (50% reduction in peak expiratory flow, FEV1 and FVC) with no difference between deep and moderate blockade. As with all patients, where neuromuscular blockade is used, postoperative reversal should be confirmed before the end of the case (to confirm return of “motor capacity” [59]). This is a central tenet of anaesthesia practice and is not solely

**Table 8** Analgesia nociception index

Author	Tool assessed	Design	Primary outcome	Results	Conclusion
Le Gall et al Sfar 2017	Analgesia Nociception Index (based on the influence of R-R interval of the ECG, expressed as an index from 0–100. An ANI value close to 100 indicates predominant parasympathetic tone, i.e. analgesia, while a value close to 0 indicates predominant sympathetic tone, i.e. nociception	Single-centre, observation, unmatched case control study comparing perioperative data from obese patients during bariatric surgery with (ANI + ve) or without (ANI –ve) ANI monitoring 30-patient retrospective cohort, 30 patients prospective	Hourly intraoperative opioid (sufentanil) use. Secondary outcomes include incidence of nausea and vomiting, respiratory distress and pain in first 24 h	<p>ANI + ve ANI-ve</p> <p>0,015 ± 0,05 0,017 ± 0,05</p> <p>Sufentanil requirement mcg/kg/h</p> <p>Pain scores</p> <p>30% of cohort had maximal pain score in first 24 h</p> <p>40% of cohort had maximal pain score in first 24 h</p> <p>PONV</p> <p>No difference</p>	ANI monitoring significantly reduced intraoperative opioid consumption, without increasing pain scores in the first 24 h postoperatively, but without a decrease in adverse effects

*ANI* Analgesia Nociception index, *PONV* postoperative nausea and vomiting, *ECG* electrocardiogram

Table 9 Point-of-care testing (ACT) specific to extracorporeal circulation

Author, journal, year	Design	Outcome	Results	Conclusion
Haas et al Eur J Anaesthesiol 2016	Prospective observational comparative study: 50 patients BMI $\geq$ 30, 50 patients BMI $\leq$ 30	To evaluate the adequacy of heparin doses in obese patients undergoing cardiac surgery by simultaneous ACT and heparin level assays  Primary: ACT and plasma heparin level at different time points Secondary: RCC transfusion	Initial dose (IU) 225.2 $\pm$ 5.6  Plasma heparin level (PHL) (IU/ml) at T1 4.48 $\pm$ 0.18  PHL at T2 3.92 $\pm$ 0.16 PHL at T3 3.07 $\pm$ 0.14 ACT (s) at T1 489.8 $\pm$ 10.7  ACT at T2 492.9 $\pm$ 12 ACT at T3 424.4 $\pm$ 7.5 Preop to ICU Hb difference (g/dl) 2.8 $\pm$ 0.2  BMI $\leq$ 30 Mean/SEM 225.2 $\pm$ 5.6  BMI $\geq$ 30 Mean/SEM 297.9 $\pm$ 5.7  $p$ value < 0.0001  < 0.0001  0.0069 0.0094 0.0369  0.266 0.204 < 0.001	Obese patients had a higher heparin concentration, which was not reflected in ACT levels after T1. ACT tended towards a plateau despite consistently raised heparin levels. Authors conclude that ACT is a poor predictor of plasma heparin concentration where heparin doses are excessive (e.g. in obese patients dosed per TBW). Although transfusion rates did not differ, obese patients had a significant drop in Hb
Vienne et al Eur J Anaesthesiol 2018	Prospective RCT in 60 obese patients—randomised to receive heparin dose 300 IU/kg TBW or 340 IU/kg IBW	Primary: ACT and plasma heparin level at different time points Total heparin dose and transfusion requirements	The correlation between ACT and plasma heparin was poor	An IBW adjusted regime of heparin dosing might be used in obese patients to avoid overdose which cannot be accurately assessed by ACT alone

BMI body mass index, TBW total body weight, IBW ideal body weight, ACT activated clotting time, RCC red cell concentrate, ICU intensive care unit, Hb haemoglobin, IU international units, IU/ml international units per millilitre, SEM standard error of the mean, T1 3 min after injection of heparin, T2 end of cardioplegia, T3 before protamine, s seconds, PHL plasma heparin level, RCT randomised control trial



applicable to the obese patient. International studies of practice, however, have suggested that this may be a neglected area of practice [63]. Meticulous attention to this standard aspect of anaesthetic management is important to mitigate against postoperative complications in this “at risk” extubation group [60].

There may be a role for deep blockade to improve surgical conditions, in which case continuous neuromuscular monitoring aiming for a post-tetanic count of 1–2 is suggested.

Although not specified in the minimum standards of anaesthesia monitoring guideline [8], depth of anaesthesia (DOA) monitoring arguably constitutes a key aspect of intraoperative monitoring of the obese patient [4, 5]. Three studies tested the depth of the anaesthesia monitor (see Table 6). Though each study tested a different monitor, all three demonstrated a reduction in recovery times. Consumption of vapour was reduced when DOA was utilised, with no increase in recall of intraoperative events. When compared to standard clinical practice, intraoperative DOA use was also associated with improved postoperative SpO<sub>2</sub>. Given the importance of postoperative pulmonary complications in this cohort, this may constitute additional justification for their use. No studies compared one DOA monitor to another. There is no evidence to direct whether one DOA monitor is superior to another.

Near-infrared spectroscopy is a non-invasive technique, which quantifies regional cerebral saturation (rSO<sub>2</sub>) as a surrogate for cerebral perfusion. Reduction in cerebral oxygenation has been associated with increased risk of neurocognitive disorders postoperatively. In a “low-risk” cohort of ASA 1 and 2 patients, a significant proportion (> 20%) experienced a critical decline in cerebral saturations (Table 7) [34]. Obese patients were at statistically increased risk of experiencing this (perhaps due to impaired compensatory mechanisms in response to pneumoperitoneum). Intraoperatively, a protocol was implemented to act on the drop in rSO<sub>2</sub> and no postoperative neurocognitive assessment was conducted so the impact of the decline cannot be ascertained.

Multimodal analgesic strategies are prioritised in the obese patient to reduce the use of

opioids perioperatively and thereby avoid the respiratory depression and nausea and vomiting which are of particular import in this context. The analgesia nociception index (ANI) has been proposed for the objective evaluation of pain perioperatively, providing an index value from 0 (predominant sympathetic tone, high level of stress, nociception) to 100 (predominant parasympathetic tone, low level of stress, analgesia). One study was retrieved (see Table 8) which found that opioid consumption was significantly reduced in the first 24 h postoperatively when ANI was used. However, this did not associate with a decrease in adverse effects. This is a novel technique, with limited evidence in the literature (our search retrieved only one additional case report) [64] but given the general preference for opioid-sparing techniques perioperatively, and the particular benefits this might have for the obese patient, this is a topic in which the evidence base will likely expand.

### Endocrine/Metabolic

Adults with BMI  $\geq$  40 are 7 times more likely to have diabetes compared those with normal weight [65]. Meticulous attention to perioperative glycaemic levels is crucial as poor control is associated with increased perioperative complications. This is of particular importance to the patient undergoing bariatric surgery, as gastric bypass surgery results in glycaemic instability, with a surgical stress response counterpointed by a rapid reduction in insulin requirements [66]. One study was retrieved which explored continuous glucose monitoring in bariatric patients undergoing sleeve gastrectomy (LSG) and Roux-en-Y bypass (LRYGB) [41]. Throughout the perioperative period, from 24 h prior to surgery for 10 consecutive days, continuous glucose measurements were compared between the two surgical groups. Significantly lower glucose concentrations were captured from postoperative day 3 in LRYGB versus LSG suggesting that the dose of anti-diabetic medication may need reduction in the former group. Although the intraoperative period was included, there was no data analysis specific to this period.

## Renal

One study described the impact of obesity on perioperative renal function. Using a matched case-control study technique within the Obesity and Surgical Outcomes database in the US, obese patients undergoing surgery were found to have a 65% increase in the odds of acute kidney injury (AKI) within 30 days [40]. Postulated theories accounting for this include the difficulties in clinically gauging volume status and accurately measuring blood pressure in obese patients. Both of these topics have been discussed in the cardiovascular section of this review.

## Drug Dosing

Obesity is associated with physiological and anthropometric changes that alter the pharmacokinetics of most drugs. As our focus was on intraoperative monitoring, we included two studies (Table 9) [38, 39] which looked at point-of-care testing and heparin dosing in obesity. In the context of extracorporeal circulation, point-of-care testing (activated clotting time) did not reliably detect the excessively high plasma heparin concentrations often achieved in the obese patient dosed according to total body weight.

## Other Considerations

Temperature management is an important aspect of intraoperative monitoring. Of particular relevance to the obese patient undergoing laparoscopic bariatric surgery is the risk of inadvertent stapling or suturing of the temperature probe, nasogastric tube, or bougie during gastrectomy or gastrojejunostomy. This matter was covered in a questionnaire issued to all bariatric surgeons in Israel, which reported on 17 cases in which one of the above was inadvertently stapled [67].

## CONCLUSIONS

Our narrative review identified 35 studies which pertained to the intraoperative monitoring of obese patients. The majority of these focused on the cardiovascular, neurological, and respiratory systems.

There are a number of limitations to our review. The literature retrieved focused almost exclusively on patients undergoing bariatric surgery, an elective procedure for which patients have been carefully selected and optimised. The in-hospital mortality in the UK for bariatric surgery has been reported at 0.04%, with a complication rate of 2.4% [68]. A preference for non-invasive monitoring techniques has been described in enhanced recovery protocols for these surgeries [42]. However, the obese patient presenting for non-bariatric, particularly emergency surgery obviously presents a different challenge for which invasive monitoring might be appropriate.

Aside from the diverse surgical settings, it is important to recognise the clinical diversity of the obesity phenotype. The “obesity paradox” has been coined to describe the apparent protective effect of obesity in certain contexts [43]. There is clearly no uniform risk profile within a BMI category.

We applied date restrictions to our search, as both practice and publication (between 2008–2012 and 2013–2018 there was a 94% increase in PubMed citations on bariatric surgery [7]) have expanded rapidly in this area. Relevant studies might have been missed on this premise.

In summary, there is a tension between the drive towards day surgery and enhanced recovery protocols which both encourage minimally invasive monitoring and the difficulty of accurately applying novel monitoring techniques to this population. This review sought to answer an ostensibly simple question (namely “what intraoperative monitoring techniques have been used in the obese patient?”) but ultimately acknowledges the polymorphic nature of both the intraoperative setting and the obesity phenotype itself.

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