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REVIEW ARTICLE/BRIEF REVIEW

Postoperative recovery after anesthesia in morbidly obese patients: a systematic review and meta-analysis of randomized controlled trials

Récupération postopératoire après anesthésie chez des patients présentant une obésité morbide: revue systématique et méta-analyse des essais randomisés contrôlés

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Abstract

Purpose *Obese patients present a challenge to safe general anesthesia because of impaired cardiopulmonary physiology and increased risks of aspiration and acute upper airway obstruction. Since studies are lacking regarding the postoperative effects on recovery from general anesthesia in morbidly obese patients, we conducted a systematic review and meta-analysis of recovery outcomes in morbidly obese patients who had undergone general anesthesia.*

Source *We systematically searched the PubMed, EMBASE™, Cochrane, and Scopus™ databases for randomized controlled trials that evaluated the outcome of anesthesia with desflurane, sevoflurane, isoflurane, or propofol in morbidly obese patients. Using a random effects model, we conducted meta-analyses to assess recovery times (eye opening, hand squeezing, tracheal extubation, and stating name or birth date), time to discharge from the postanesthesia care unit (PACU), and the incidence and severity of postoperative nausea and vomiting (PONV).*

Principal findings *We reviewed results for 11 trials and found that patients given desflurane took less time: to respond to commands to open their eyes (weighted mean difference [WMD] −3.10 min; 95% confidence interval (CI): −5.13 to −1.08), to squeeze the investigator's hand (WMD −7.83 min; 95% CI: −8.81 to −6.84), to be prepared for tracheal extubation (WMD −3.88 min; 95%*

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Author contributions *Ka-Wai Tam* and *Feng-Lin Liu* devised the study. *Ka-Wai Tam*, *Feng-Lin Liu*, and *Yih-Giun Cherng* extracted, analyzed, and interpreted the data. *Ka-Wai Tam* and *Feng-Lin Liu* wrote the first draft. All authors contributed to subsequent versions.

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CI: −7.42 to −0.34), and to state their name (WMD −7.15 min; 95% CI: −11.00 to −3.30). We did not find significant differences in PACU discharge times, PONV, or the PACU analgesic requirement.

Conclusion *Postoperative recovery was significantly faster after desflurane than after sevoflurane, isoflurane, or propofol anesthesia in obese patients. No clinically relevant differences were observed regarding PACU discharge time, incidence of PONV, or postoperative pain scores. The systematic review was registered with PROSPERO (CRD42014009480).*

Résumé

Objectif *Les patients obèses constituent un défi pour une anesthésie générale sécuritaire en raison d'une physiologie cardiopulmonaire altérée et de risques accrus d'aspiration et d'obstruction aiguë des voies aériennes hautes. Considérant que l'on manque d'études sur la récupération des effets postopératoires de l'anesthésie générale chez des patients présentant une obésité morbide, nous avons effectué une revue systématique et une méta-analyse des critères de jugement de la récupération chez ces patients ayant une obésité morbide et ayant subi une anesthésie générale.*

Source *Nous avons effectué une recherche systématique dans les bases de données PubMed, MEDLINE™, Cochrane et Scopus™ pour identifier des études randomisées et contrôlées qui avaient évalué les aboutissements de l'anesthésie par desflurane, sévoflurane, isoflurane ou propofol chez des patients ayant une obésité morbide. Au moyen d'un modèle d'effets aléatoires, nous avons réalisé des méta-analyses pour évaluer les temps de récupération (ouverture des yeux, serrement de main, extubation trachéale, indication du nom ou de la date de naissance), le temps écoulé jusqu'au congé de l'unité de soins post anesthésie (salle de réveil) et l'incidence et la sévérité des nausées et vomissements postopératoires.*

Constatations principales *Nous avons analysé les résultats de 11 études et avons constaté que les patients ayant reçu du desflurane prenaient moins de temps à: répondre à l'ordre d'ouvrir les yeux (différence moyenne pondérée [DMP] −3,10 min; intervalle de confiance [IC] à 95 %: −5,13 à −1,08), à serrer la main de l'investigateur (DMP −7,83 min; IC à 95 %: −8,81 à −6,84), à être prêt pour l'extubation trachéale (DMP −3,88 min; IC à 95 %: −7,42 à −0,34) et à donner leur nom (DMP −7,15 min; IC à 95 %: −11,00 à −3,30). Nous n'avons pas trouvé de différences significatives dans les délais de congé de la salle de réveil, ni sur les plans des nausées et vomissements post opératoires ou des besoins en analgésiques en salle de réveil.*

Conclusion *La récupération postopératoire a été significativement plus rapide après desflurane qu'après une anesthésie par sévoflurane, isoflurane ou propofol chez des patients obèses. Aucune différence cliniquement pertinente n'a été observée concernant les délais de congé de la salle de réveil, l'incidence des nausées et vomissements postopératoires, ou des scores de douleur postopératoire. La revue systématique a été enregistrée dans PROSPERO (CRD42014009480).*

The number of morbidly obese patients presenting for general anesthesia is increasing.[1] Obese patients present a challenge regarding general anesthesia because of altered cardiopulmonary physiology, including decreased functional residual capacity, increased oxygen consumption and cardiac output, as well as their associated pathologies, such as diabetes mellitus, obstructive sleep apnea, and hypertension.[1] In addition, obese patients are at a high risk of both aspiration and acute upper airway obstruction in perioperative settings.[2] Therefore, appropriate postoperative respiratory function, optimal alertness, hemodynamic stability, and avoidance of pain and postoperative nausea and vomiting (PONV) are needed to guarantee favourable outcomes in these patients.[3]

The volatile anesthetics, desflurane and sevoflurane, have significantly lower blood/gas partition coefficients (0.45 and 0.65, respectively) compared with isoflurane (1.4) or halothane (2.4), predicting greater intraoperative control and more rapid recovery from anesthesia.[4,5] More rapid recovery might be associated with earlier maintenance of patent airways, more effective protection against aspiration, and greater oxygenation.[6] Studies of healthy volunteers have indicated that recovery from anesthesia with desflurane is faster than that with sevoflurane.[7] Total intravenous anesthesia applied with propofol is associated with rapid recovery and a lower incidence of PONV compared with other agents.[8] It is also an affordable choice that facilitates maintenance of general anesthesia in morbidly obese patients. Nevertheless, only a limited number of studies have been conducted on its postoperative effects in morbidly obese patients on recovery from general anesthesia. Therefore, we conducted a systematic review and meta-analysis of the evidence available to date to determine recovery outcomes after administering desflurane,

sevoflurane, isoflurane, and propofol to morbidly obese patients undergoing general anesthesia.

Methods

Inclusion criteria

Our analysis included only previous randomized controlled trials (RCTs) that evaluated the outcome of administering desflurane, sevoflurane, isoflurane, or propofol to morbidly obese patients undergoing general anesthesia. Studies were included if they (1) were RCTs; (2) included obese patients with body mass indices (BMIs) $\geq$ 30 kg·m^{-2} undergoing general anesthesia or total intravenous anesthesia; and (3) contained any outcome of interest (recovery profiles or the incidence and severity of PONV). Previous RCTs were excluded from our meta-analysis based on the following criteria: (1) emergency operations; (2) patients $<$ 18 yr of age; (3) the appropriate data could not be extracted or calculated from the published results and could not be obtained from the authors upon request; (4) apart from the experimental anesthetic, the patients in the various groups were treated with different anesthesia techniques; or (5) there was duplicate reporting of patient cohorts.

Search strategy and study selection

We performed a comprehensive literature search of several databases, including PubMed, EMBASE™, Scopus™, the Cochrane Central Register of Controlled Trials, and the ClinicalTrials.gov registry (http://clinicaltrials.gov/). The focused PICO (**P**opulation, **I**ntervention, **C**omparison, **O**utcome) question was: "In case of morbidly obese patients undergoing general anesthesia, how does desflurane compare to sevoflurane, isoflurane, and propofol in terms of the recovery outcomes?" The keywords used for the medical subject heading and free-text searches were *obese, overweight, bariatric surgery, body mass index, anesthesia, anesthetic, desflurane, sevoflurane, isoflurane, propofol, total intravenous anesthesia,* and *TIVA*. The related citations in the PubMed search tool were used to broaden each search. We reviewed all the abstracts, study reports, and related citations that were retrieved. No language restrictions were applied. The last search was performed in November 2014.

Data extraction

Two reviewers independently extracted the baseline and outcome data, including the study design, participant characteristics, inclusion and exclusion criteria, applied anesthesia techniques, operative and postoperative parameters, and complications. If there were any inconsistencies between the findings of the two reviewers, they were resolved by a third reviewer.

Methodological quality appraisal

The quality of the studies was assessed using the "risk of bias" method recommended by the Cochrane Collaboration.[9] Several domains were assessed, including the adequacy of the randomization, allocation concealment, blinding of the patients, and outcome assessors; the length of the follow-up period; the reporting of study dropouts; the performance of an intention-to-treat analysis; and freedom from selection reporting.

Outcomes and statistical analysis

The primary outcome was the time from ceasing anesthetic administration to responding to the command to open eyes, squeezing the investigator's hand, tracheal extubation, and stating the name or birth date. Secondary outcomes included time to discharge from the postanesthesia care unit (PACU), the incidence and severity of PONV, mean oxygen saturation, postoperative pain, and hemodynamics. All data were entered and analyzed using Review Manager, Version 5.2 (Cochrane Collaboration, Oxford, England, UK). The meta-analysis was performed according to PRISMA guidelines.[10] When necessary, standard deviations were estimated based on the confidence intervals (CI), standard errors, or ranges provided in the previous studies.[11] Effect sizes of dichotomous outcomes were presented as risk ratios (RRs), and the mean difference was reported for continuous outcomes with a 95% CI. A pooled estimate of the RRs was computed by applying the DerSimonian and Laird random effects model.[12] This model provides an appropriate estimate of the average treatment effect when trials are statistically heterogeneous. It typically yields relatively wide CIs, resulting in a more conservative statistical claim.

To evaluate the statistical heterogeneity and the inconsistency of treatment effects across the studies, the Cochran's Q test and I^2 statistics were used, respectively. Statistical significance was set at 0.10 for the Cochran's Q tests. The proportion of the total outcome variability that was attributable to the variability across the studies was quantified as I^2.

Results

Trial characteristics

The flowchart in Fig. 1 indicates the process that was used to screen and include randomized controlled trials (RCTs).

Our initial search yielded 2,843 citations. Based on the screening criteria for titles and abstracts, 2,712 citations were excluded. After reviewing the full text of the remaining 131 reports, only 11 eligible RCTs fit our inclusion criteria and were selected for the study.[3,13-22]

All 11 studies were published in English during 2000 to 2013, and the sample sizes ranged from 28 to 90 patients. Among these studies, De Baerdemaeker *et al*. evaluated 50 obese patients and reported distinct outcome measurements in two studies.[3,15] In all trials, the recruited patients were American Society of Anesthesiologists (ASA) status I–III who underwent general anesthesia with endotracheal intubation. In addition, in all trials except one, the patients underwent elective bariatric operations; the one exception included obese patients who underwent intra-abdominal, orthopedic, or other surgery.[14] The mean BMI of the patients ranged from 37.7 to 54.0 $kg \cdot m^{-2}$. In seven trials, desflurane was compared with sevoflurane for maintenance of anesthesia.[3,13-18] Two studies compared the recovery profiles of patients given sevoflurane *vs* isoflurane for maintenance of anesthesia.[19,20] Another two studies compared the recovery parameters of patients given intravenous anesthesia with those given propofol and inhalational anesthesia.[21,22] The average anesthetic duration ranged from 112 to 275 min. After induction, anesthesia was maintained using a volatile anesthetic or propofol, with anesthetic delivery at 1.0 minimal alveolar concentration (MAC), a bispectral index (BIS) value of 40–60, or clinical demands. The patient characteristics, anesthetic techniques, and surgical procedures used in the 11 trials are listed in the Table.

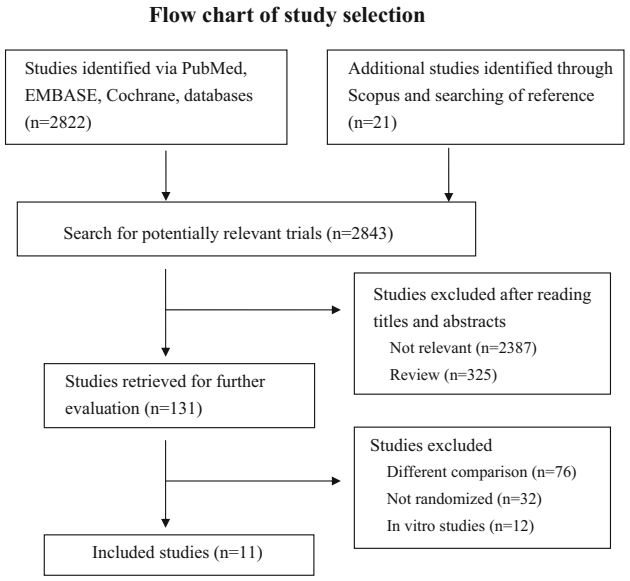

Fig. 1 Flowchart describing selection of the randomized controlled trials for our meta-analysis

Our assessment of the methodological quality of the 11 included RCTs is summarized in Fig. 2. Three studies used acceptable methods of randomization,[17,18,20] and four studies clearly described the method of allocation concealment.[3,13,20,21] Three studies did not mention the blinding procedure,[15,19,22] and only one reported no blinding of the outcome assessors.[18] Eight studies incorporated an intention-to-treat analysis,[3,13,15,16,18-20,22] and in all trials, an acceptable number of patients (< 20%) withdrew during the follow-up periods . Selective reporting was estimated as low risk in all trials. Other biases included unbalanced patient numbers between groups[19] and lack of investigator blinding in the assessments before PACU admission.[21]

Recovery times required for eye opening, hand squeezing, extubation, and name stating

Desflurane vs sevoflurane

Seven RCTs compared recovery outcomes of patients given desflurane *vs* sevoflurane for maintenance of anesthesia,[3,13-18] and six trials evaluated the time required for eye opening.[13-18] We observed a statistically significant difference in time required for eye opening between the two treatment groups (weighted mean difference [WMD]: −3.10 min; 95% CI: −5.13 to −1.08). Patients who received desflurane required a significantly shorter time for eye opening than patients who received sevoflurane. We also observed significant heterogeneity across the studies (I^2 = 84%; Chi square = 30.82; P < 0.0001). Two studies investigated the time required for hand squeezing.[13,16] We observed a statistically significant difference in time required for hand squeezing between the two treatment groups (WMD: −7.83 min; 95% CI: −8.81 to −6.84). Patients given desflurane required a significantly shorter time for hand squeezing than patients given sevoflurane. No heterogeneity was observed across the studies (I^2 = 0%). Five trials examined the time required for extubation. [13-17] We observed a statistically significant difference in time required for extubation (WMD: −3.88 min; 95% CI: −7.42 to −0.34). Patients given desflurane required a significantly shorter time for tracheal extubation than patients given sevoflurane. We observed significant heterogeneity across the studies (I^2 = 94%; Chi square = 67.33; P < 0.00001). Four studies evaluated the time required for name stating.[13,15,16,18] Patients given desflurane required a significantly shorter time for name stating than patients given sevoflurane (WMD: −7.15 min; 95% CI: −11.00 to −3.30). Heterogeneity was also significantly high across the studies (I^2 = 93%; Chi square = 30.46; P < 0.00001) (Fig. 3).

Table Characteristics of the selected randomized controlled trials

Study	Inclusion criteria	No. of patients, by anesthetic (% male)	Age, by anesthetic (yr)	BMI ($kg \cdot m^{-2}$)	Anesthesia technique
De Baerdemaeker *et al.*[3]	BMI $\geq$ 35 $kg \cdot m^{-2}$, laparoscopic gastric banding	D: 25 (8) S: 25 (16)	D: 35 (8) S: 38 (12)	D: 41 (5) S: 41 (6)	Induction with TCI remifentanil, propofol 2 $mg \cdot kg^{-1}$ of IBW, and rocuronium 0.9 $mg \cdot kg^{-1}$ of IBW. Maintained with D or S by BIS 45–55
De Baerdemaeker *et al.*[15]	BMI $\geq$ 30 $kg \cdot m^{-2}$, laparoscopic gastroplasty	D: 25 (8) S: 25 (16)	D: 35 (8) S: 38 (12)	D: 41 (5) S: 41 (6)	Induction with TCI remifentanil, propofol 2 $mg \cdot kg^{-1}$ of IBW, and rocuronium 0.9 $mg \cdot kg^{-1}$ of IBW. Maintained with D or S by BIS 45–55
La Colla *et al.*[13]	ASA II–III, BMI $\geq$ 35 $kg \cdot m^{-2}$, elective biliointestinal bypass surgery	D: 14 (57) S: 14 (57)	D: 40.0 (8.8) S: 34.3 (13.9)	D: 53.3 (5.9) S: 47.9 (1.6)	TCI remifentanil, then fibreoptic intubation. After intubation, induction with propofol 2 $mg \cdot kg^{-1}$. Maintained with 6% D or 2% S by BIS 45–55
Arain *et al.*[14]	ASA II–III, BMI $\geq$ 35 $kg \cdot m^{-2}$, elective surgery > 2 hr	D: 20 (95) S: 20 (90)	D: 62.1 (42–83)† S: 60.3 (36–73)†	D: 38.5 (34–47)† S: 37.7 (35–42)†	Induction with fentanyl at 2 $\mu g \cdot kg^{-1}$, propofol 1.5–2.0 $mg \cdot kg^{-1}$, and SCC 1.25–1.5 $mg \cdot kg^{-1}$ of IBW. Maintained with D or S by BIS 45–50
Strum *et al.*[16]	ASA II–III, BMI $\geq$ 35 $kg \cdot m^{-2}$, open gastrointestinal bypass surgery	D: 25 (24) S: 25 (16)	D: 41.4 (9.6) S: 42.9 (9.7)	D: 53 (11) S: 54 (10)	After epidural catheter placement, induction with fentanyl and propofol, SCC. Maintained with 6% D or 2% S
Vallejo *et al.*[17]	BMI $\geq$ 35 $kg \cdot m^{-2}$, laparoscopic gastroplasty	D: 35 S: 35	D: 44.6 (9.6) S: 41.4 (10.0)	D: 47.3 (6.3) S: 47.6 (6.7)	Induction with fentanyl 100–250 μg, rocuronium 5 mg, and propofol 2 $mg \cdot kg^{-1}$, SCC 15 $mg \cdot kg^{-1}$. Maintained with 6% D or 2% S
Kaur *et al.*[18]	ASA II–III, BMI $\geq$ 35 $kg \cdot m^{-2}$, laparoscopic bariatric surgery	D: 20 (40) S: 20 (25)	D: 37.75 (0.8) S: 39.45 (9.2)	D: 49.23 (10.5) S: 52.33 (6.75)	Induction with fentanyl 1–2 $\mu g \cdot kg^{-1}$, propofol 1.0–1.5 $mg \cdot kg^{-1}$, and atracurium 0.5 $mg \cdot kg^{-1}$. Maintained with N_2O and D or S by BIS 40–60
Sollazzi *et al.*[19]	BMI $\geq$ 45 $kg \cdot m^{-2}$, biliopancreatic diversion	I: 60 S: 30			Induction with thiopental 2–3 $mg \cdot kg^{-1}$, fentanyl 2–3 $\mu g \cdot kg^{-1}$, SCC, and atracurium 0.4 $mg \cdot kg^{-1}$. Maintained with I or S according to clinical necessity
Torri *et al.*[20]	ASA II–III, BMI $\geq$ 35 $kg \cdot m^{-2}$, laparoscopic gastric banding	I: 15 (6.7) S: 15 (6.7)	I: 36 (24–63)† S: 36 (21–51)†	I: 42 (36–54)† S: 43 (35–54)†	Induction with fentanyl 1 $\mu g \cdot kg^{-1}$, thiopental 6 $mg \cdot kg^{-1}$, SCC 1 $mg \cdot kg^{-1}$, atracurium 0.4 $mg \cdot kg^{-1}$. Maintained using I or S according to clinical necessity

Table continued

Study	Inclusion criteria	No. of patients, by anesthetic (% male)	Age, by anesthetic (yr)	BMI ($kg \cdot m^{-2}$)	Anesthesia technique
Juvin *et al.*[21]	BMI ≥ 35 $kg \cdot m^{-2}$, laparoscopic gastroplasty	D: 12 (25) I: 12 (8.3) P: 12 (8.3)	D: 40.1 (7) I: 36.5 (8.5) P: 39.7 (10.4)	D: 46.5 (5.3) I: 47.5 (4.9) P: 44.3 (4.0)	Induction with TCI propofol 8 $\mu g \cdot mL^{-1}$ and SCC 1.2 $mg \cdot kg^{-1}$. Maintained with 50% N_2O and D or I or P by BIS 45–55
Salihoglu *et al.*[22]	ASA I–II, bariatric operation	S: 20 (60) P: 20 (45)	S: 47.1 (14.2) P: 45.9 (14.3)	S: 50 (35–64)† P: 50 (35–64)†	S: Induction with S breathing, atracurium 0.6 $mg \cdot kg^{-1}$, and alfentanil 50 $\mu g \cdot kg^{-1}$. Maintained with 1–2% S. P: Induction with P 21 $mg \cdot kg^{-1} \cdot hr^{-1}$, atracurium 0.6 $mg \cdot kg^{-1}$, and alfentanil 50 $\mu g \cdot kg^{-1}$. Maintained with P 6 $mg \cdot kg^{-1} \cdot hr^{-1}$

ASA = American Society of Anesthesiologists; BIS = bispectral index; BMI = body mass index; D = desflurane; I = isoflurane; IBW = ideal body weight; N_2O = nitrous oxide; P = propofol; S = sevoflurane; SCC = succinylcholine; TCI = target continuous infusion

Data are presented as *n* (%) and mean (SD); data identified with † are presented as mean (range)

Fig. 2 Risk of bias. Green indicates low risk of bias; red indicates high risk of bias; blank indicates unclear risk of bias

Isoflurane vs sevoflurane

Two RCTs compared the recovery outcomes of patients given isoflurane *vs* sevoflurane for maintenance of anesthesia.[19,20] The sevoflurane groups required a significantly shorter time for tracheal extubation than the isoflurane groups (WMD: −7.48 min; 95% CI: −4.45 to −10.52). Moderate heterogeneity between the two groups was observed (I^2 = 55%; Chi square = 2.23; P = 0.14) (Fig. 4). In the study by Torri et *al.*,[20] the patients in the sevoflurane group required a significantly shorter mean (SD) time for eye opening than those in the isoflurane group [8.9 (3.9) min *vs* 15.6 (6.9) min, respectively; $P <$ 0.001] and similarly for hand squeezing [12.2 (4.0) min *vs* 21.9 (7.1) min, respectively; $P < 0.001$].[20]

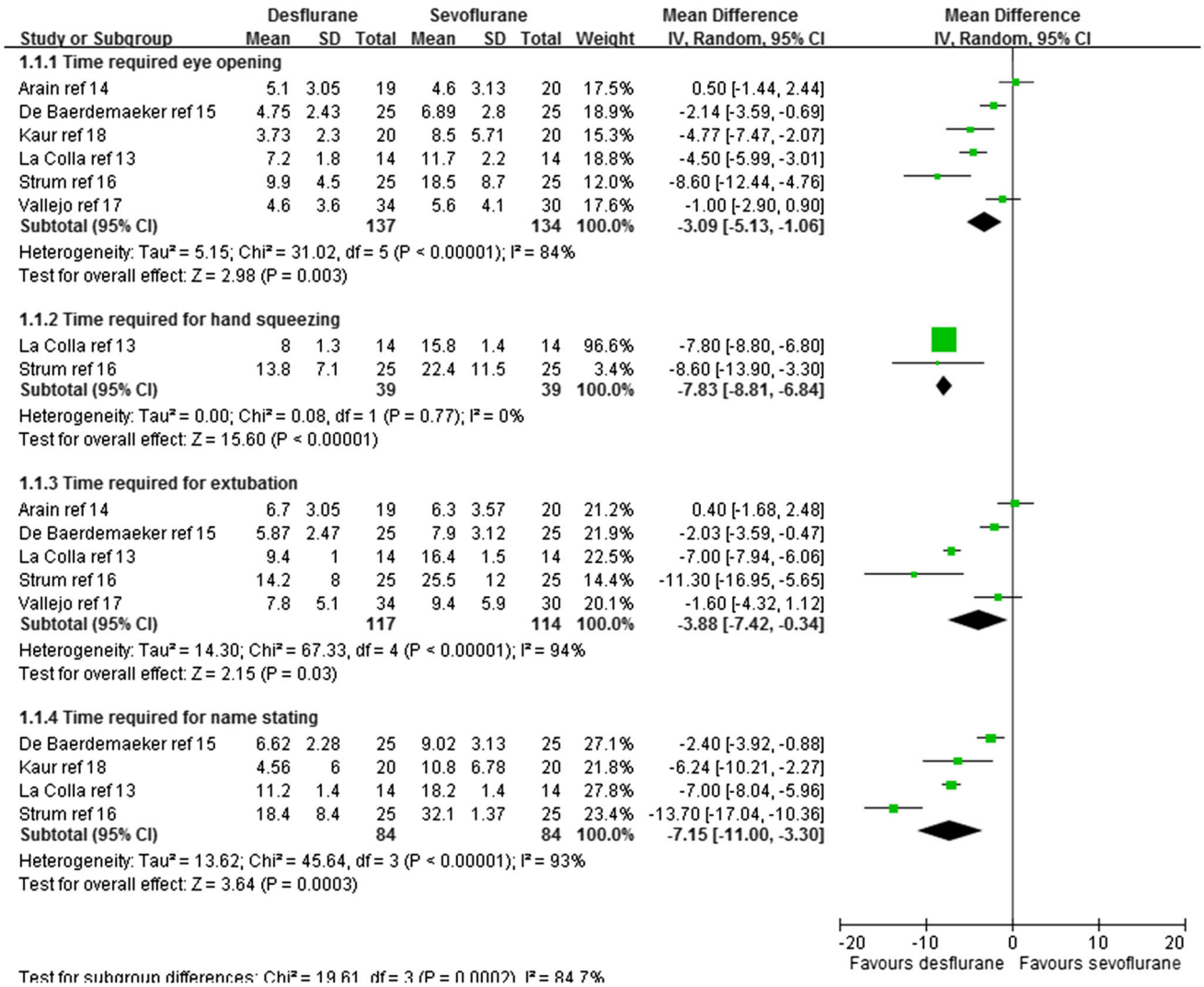

Fig. 3 Forest plot comparing the desflurane with the sevoflurane groups regarding the time required (min) for 1.1.1) eye opening; 1.1.2) hand squeezing; 1.1.3) extubation; and 1.1.4) name stating

Propofol vs isoflurane, sevoflurane, and desflurane

Two RCTs compared propofol with other inhalational agents and revealed that patients who were given desflurane required a significantly shorter mean (SD) recovery time [4.2 (1.3) min] for eye opening than patients given isoflurane [10.3 (4.9) min] or propofol [10.7 (6.9) min].[21] Nevertheless, no significant difference was observed between patients treated with propofol or sevoflurane.[22] In addition, the mean (SD) time required for tracheal extubation in the desflurane groups [5.6 (1.4) min] was significantly shorter than that in the isoflurane groups [12.2 (6.0) min; $P < 0.05$] or the propofol groups [13.2 (7.6) min; $P < 0.05$]. No significant difference was observed between the isoflurane and propofol groups.[21] Patients who were given desflurane also required a significantly shorter mean (SD) time [6.0 (1.8) min] for name stating than patients who were given propofol [14.6 (8.7) min; $P < 0.05$] or isoflurane [14 (7.0) min; $P < 0.05$].[21] No significant difference was observed in patients treated with propofol, sevoflurane, or isoflurane.[21,22]

Postanesthesia care unit discharge times

Five RCTs evaluated the PACU discharge times. Three RCTs compared desflurane with sevoflurane,[13,16,17] one compared sevoflurane with isoflurane,[20] and one compared propofol with inhalational gas.[21] The results of the PACU discharge times in two RCTs that compared desflurane with sevoflurane are illustrated in Fig. 5.[13,17] No significant difference was observed in the time required for PACU discharge between the two treatment groups (WMD: 1.28 min; 95% CI: −24.66 to 27.21). We did not include the results of the Strum *et al*. study because no standard

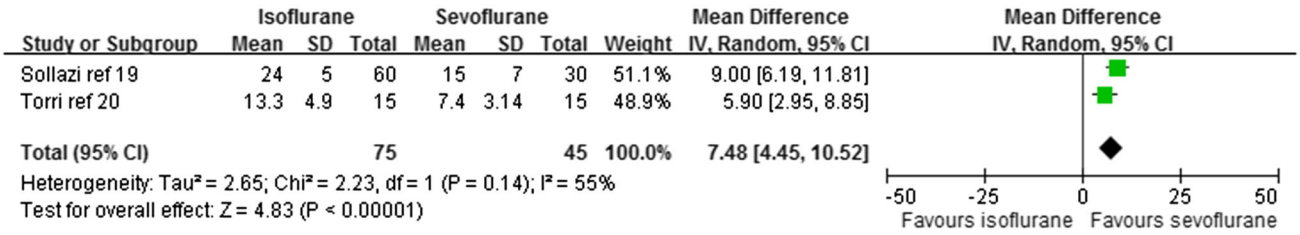

Fig. 4 Forest plot comparing the isoflurane and sevoflurane groups regarding the time required (min) for extubation

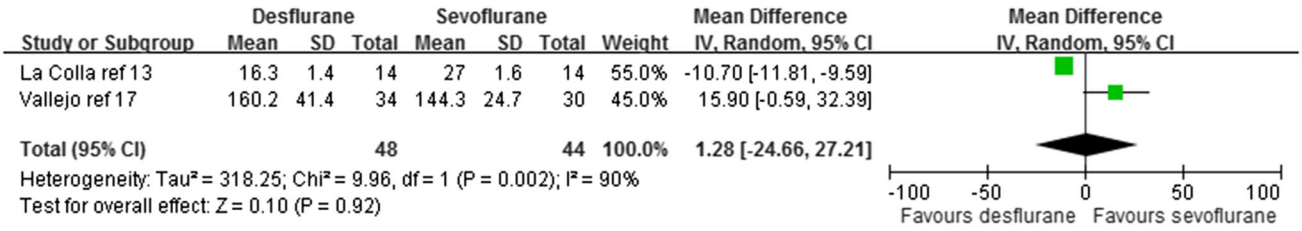

Fig. 5 Forest plot comparing the isoflurane with the sevoflurane groups regarding the PACU discharge time (min). PACU = postanesthesia care unit

deviation of discharge time was provided. In this study, the difference in time required for PACU discharge between the desflurane (162 min; range 84–538) and sevoflurane (160 min; range 90–429) groups was nonsignificant.[16]

In the Torri *et al*. study, patients who were given sevoflurane required a significantly shorter time for PACU discharge than patients who were given isoflurane. The median interquartile range [IQR] time for PACU discharge in the sevoflurane group was 15 [10–18] min *vs* 27 [20–30] min in the isoflurane group ($P = 0.0005$).[20]

The study of Juvin *et al.* comparing desflurane, isoflurane, and propofol indicated a trend toward shorter PACU stays for the desflurane group. Nevertheless, the study did not indicate statistically significant mean (SD) time differences among the three groups [126 (56) min, 180 (72) min, and 198 (109) min for patients who received desflurane, isoflurane, and propofol, respectively].[21]

Postoperative nausea and vomiting

Four studies included PONV measurements; three compared desflurane with sevoflurane,[3,16,17] and one compared desflurane, isoflurane, and propofol.[21] Among these studies, one RCT used a numerical scoring system for PONV;[17] one study provided episodes of nausea and vomiting,[3] and two RCTs did not provide data on the incidence or describe the method of PONV evaluation.[16,21] Therefore, we did not pool the PONV data in the meta-analysis. Nevertheless, all four studies indicated no significant difference in the PONV incidence among the groups.

Mean oxygen saturation, postoperative pain, and hemodynamics

Four studies included mean oxygen saturation measurements in the PACU; three of these compared desflurane and sevoflurane,[3,16,17] and one compared desflurane, isoflurane, and propofol.[21] All studies indicated satisfactory oxygen saturation in most patients. The Baerdemaeker *et al*. study revealed satisfactory SpO_2 profiles in both the sevoflurane and desflurane groups without serious hypoxic incidents; however, the mean (SD) SpO_2 at 120 min was statistically significantly lower in the sevoflurane group [96.2% (2.2%)] than in the desflurane group [97.2% (1.5%)].[3] The Strum *et al*. study comparing oxygen saturation levels on arrival at the PACU found significantly higher mean (SD) SpO_2 in patients given desflurane [97.0% (2.4%)] than in patients given sevoflurane [94.8% (4.4%); $P = 0.035$].[16] Moreover, Juvin *et al*. reported that the median [IQR] values of SpO_2 at PACU admission were 97.5% [95–99%], 95.5% [86–98%], and 96% [84–99%] after anesthesia with desflurane, isoflurane, and propofol, respectively. The SpO_2 values were significantly higher after desflurane than after isoflurane or propofol[21]; however, in the Vallejo *et al*. study, all patients maintained their $SpO_2 > 98\%$, and there was no difference between the desflurane and sevoflurane groups.[17]

Seven studies compared postoperative pain based on visual analogue scores (VAS) or on postoperative analgesic requirement.[3,14,16,17,19-21] No significant differences were observed in the VAS or PACU analgesic requirements

among the groups treated with desflurane, sevoflurane, isoflurane, or propofol.

Six studies compared intraoperative or postoperative hemodynamics, including heart rate and blood pressure. Five studies compared inhalational gas,[15-17,19,20] and one study compared propofol with sevoflurane.[22] The five studies that compared desflurane with sevoflurane or isoflurane with sevoflurane indicated no significant difference in hemodynamic parameters, except that more episodes of hypotension were associated with the sevoflurane group in the Baerdemaeker *et al*. report.[14,15,17,19,20] Intraoperative and early postoperative mean arterial pressures were significantly lower in the propofol group than in the sevoflurane group.[22]

Discussion

We systematically reviewed and evaluated the postoperative recovery profiles of the inhalational and intravenous anesthetics, desflurane, sevoflurane, isoflurane, and propofol, in morbidly obese patients. The results indicated that the times required for eye opening, hand squeezing, extubation, and name stating were significantly shorter in the patients given desflurane than in those given sevoflurane, isoflurane, or propofol. No significant difference was observed among the groups regarding the PACU discharge time, PONV incidence, or analgesia requirement. The results of mean oxygen saturation without oxygen supplement at the time of arrival at or discharge from the PACU indicated higher mean oxygen saturation in the desflurane groups than in the other anesthetic groups. Patients in the propofol groups also exhibited significantly lower mean arterial pressure than patients in the sevoflurane group intraoperatively or during the early PACU period.

Generally, the fat solubility of anesthetics plays a critical role in the time to wake up. Cork *et al.* showed that the fat solubility of inhaled and intravenous anesthetics did not influence the anesthetic emergence or discharge time in morbidly obese patients.[23] The blood-gas solubility was a more crucial factor influencing the emergence time than fat solubility.[14] Rapid recovery from desflurane anesthesia has been shown in a meta-analysis of studies on postoperative measurements of desflurane and sevoflurane.[24-27] Although studies conducted on morbidly obese populations are limited, maintaining anesthesia with desflurane has been suggested because of its low blood/gas partition coefficient, which results in a more rapid and consistent recovery profile in morbidly obese patients.[28] Our meta-analysis results were compatible with the current evidence.

Among the seven studies that compared desflurane with sevoflurane, six indicated a shorter recovery time in patients given desflurane, whereas one indicated no significant difference between desflurane and sevoflurane.[14] Many factors, such as gas concentration, surgery duration, and the patient's BMI, can influence the emergence or recovery time. Katznelson *et al.* also showed that recovery time from general anesthesia in both obese and non-obese patients can be accelerated using either isocapnic or hypercapnic hyperpnea.[29,30] Eger *et al*. indicated that differences in time to wake up were minimal when lower amnestic concentrations of desflurane and sevoflurane were used.[31] Some studies in our meta-analysis maintained anesthesia depth at BIS 45 or 1.0 MAC and titrated to BIS 60 or 0.5 MAC near the end of surgery, which might have reduced the difference in recovery time among the groups.[13,14,17]

The mean durations of anesthesia time in all studies were within the range of two to four hours. Desflurane has lower solubility in blood than sevoflurane, and longer duration of surgery can be assumed to lead to larger differences in recovery outcomes. In a meta-analysis conducted by Ebert *et al*. comparing sevoflurane with isoflurane, the recovery time did not differ in studies with surgeries shorter than one hour. Nevertheless, in studies with surgeries lasting one to three hours, recovery time was shorter in the sevoflurane groups and significantly shorter in studies with surgeries lasting three to five hours.[32] Desflurane has a significantly lower blood/gas partition coefficient than sevoflurane or isoflurane,[4,5] which results in a shorter recovery time in morbidly obese patients undergoing longer surgery. McKay *et al*. compared recovery times with desflurane *vs* sevoflurane for maintenance of anesthesia in patients with BMIs ranging from 18.3 to 40.2 $kg{\cdot}m^{-2}$ and various durations of surgery. They determined that a longer duration of sevoflurane anesthesia significantly prolonged the airway reflex recovery time, whereas desflurane anesthesia had only a minimal effect on airway recovery time.[33]

The mean BMI of patients enrolled in most of the studies in our meta-analysis ranged from 41 to 54 $kg{\cdot}m^{-2}$, and only one study enrolled patients with a mean BMI of 38.1 $kg{\cdot}m^{-2}$.[14] McKay *et al.* showed that a longer airway-reflex recovery time in patients who were given sevoflurane was correlated with a higher BMI, whereas there was no significant correlation between the airway-reflex recovery time and BMI in patients who were given desflurane.[33] In addition, in a study that enrolled overweight patients undergoing minor peripheral procedures, no significant difference was observed in tracheal extubation time between the desflurane and propofol groups.[34] This might explain the nonsignificant recovery results presented in the study of Arain *et al*., which was the only study reporting a mean BMI of 38.1 $kg{\cdot}m^{-2}$. In contrast, other studies reporting a higher mean

BMI (> 40 $kg \cdot m^{-2}$) indicated that desflurane was associated with shorter recovery times.

Our findings regarding the PACU discharge time after desflurane and sevoflurane anesthesia are consistent with previously published comparative studies, i.e., faster emergence from desflurane *vs* sevoflurane anesthesia failed to lead to an earlier discharge from the PACU.[27,35-37] On the other hand, the PACU discharge time is affected by many non-medical factors, such as absence of a nurse to transfer the patient to the ward or waiting to meet the anesthesiologist before leaving the PACU, which may explain the uncoordinated results between emergence and the PACU discharge time after desflurane and sevoflurane anesthesia.

The significant heterogeneity among our selected studies was attributable to various factors. First, the characteristics of the participants varied. For example, in the Arain *et al.* study, the participants were predominantly male.[14] Second, the surgical interventions adopted in the studies were not identical. One of the studies selected patients who did not undergo bariatric surgery, whereas the other studies included only patients who had bariatric surgery.[14] Clinical factors other than the various experimental inhalation agents also exaggerated the heterogeneity of this study. Such factors included opioid doses, the experience level of the anesthesiologists, the anesthesia being maintained according to BIS or MAC, and the use of nitrous oxide. Third, the outcome measure of time required for extubation was not completely standardized. Some studies used train-of-four with clinical criteria, whereas others used solely clinical criteria.[13,14,17]

This study had limitations. First, the sample sizes used in some of the RCTs were relatively small. Although a meta-analysis can compensate for this limitation to some extent, the statistical power of the results remains limited. Second, several studies did not report the details of sequence generation and allocation concealment. Third, several studies did not report the details of the outcome measurements, potentially limiting inferences based on our analysis. Finally, whereas the usual definition of morbidly obese is either a BMI > 35 or a BMI > 30 $kg \cdot m^{-2}$ together with obesity-related health complications, our inclusion criteria specified studies that included patients with a BMI > 30 $kg \cdot m^{-2}$. Although it is possible that one or more studies might have included a small number of patients who would not normally be classified as morbidly obese, the mean BMI was $\geq$ 37.5 $kg \cdot m^{-2}$ in all studies. Therefore, in our view, our results do apply to morbidly obese patients as they are usually defined.

In conclusion, our meta-analysis indicated that recovery was significantly faster in the desflurane groups than in the sevoflurane, isoflurane, and propofol groups in obese adult patients who underwent major abdominal surgery. Although no clinically relevant difference was observed in the PACU discharge time, incidence of PONV, or postoperative pain scores, patients who were given desflurane exhibited higher oxygen saturation on entry to or during stays in the PACU. Thus, in morbidly obese patients, we suggest that desflurane should be considered as the inhaled anesthetic because of its more rapid and consistent recovery profile.

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