EGYPTIAN JOURNAL OF ANAESTHESIA
2023, VOL. 39, NO. 1, 322–328
https://doi.org/10.1080/11101849.2023.2190865

Propofol/dexmedetomidine Versus Desflaurane Effects on Post Hepatectomy Hepatocellular Injury

Ola A. Saad Ali Lashin, Mohamed M. Abd- Elfattah Ghoneim, Hany M. Mohamed Elzahaby, Mohamed M. Mohamed Awad Rashed and Sahar M. Talaat Taha

Department of Anesthesiology, Intensive Care and pain management Faculty of Medicine, Ain Shams University, Cairo, Egypt

ABSTRACT

Objective: The Pringle maneuver used during hepatectomy causes ischemic reperfusion injury to the liver remnant. In this study, we compared the effect of maintenance of general anesthesia with propofol dexmedetomidine intravenous infusion versus desflurane inhalational anesthesia on post-hepatectomy hepatocellular injury in patients undergoing partial hepatectomy during the first six postoperative days.

Methods: Group A (15 patients) received total intravenous anesthesia with a combination of propofol and dexmedetomidine for anesthesia maintenance, and group B (15 patients) received desflurane for anesthesia maintenance. Alanine aminotransferase (ALT), aspartate aminotransferase (AST), serum albumin, serum bilirubin, prothrombin time (PT), and international normalized ratio (INR) were measured before surgery and at 1, 3, and 6 days after surgery.

Results: Transaminase levels, which were comparable in both groups, peaked between the first and the third postoperative days. The peak ALT was 224.27 ± 29.7 and 318.20 ± 52.5 U/L in group A and group B, respectively ($P < 0.001$). The peak AST was 265.60 ± 22.3 U/L in group A and 349.27 ± 56.1 U/L in group B ($P < 0.001$). Albumin levels at day 1 showed no significant differences between both groups, but at days 3 and 6, group A showed significantly higher albumin levels than group B. Other liver function tests including serum albumin, total and direct bilirubin, PT, and INR showed lower values in the propofol/dexmedetomidine group.

Conclusion: The main finding of this study is that propofol/dexmedetomidine as a technique for the maintenance of anesthesia resulted in less hepatocellular injury and better hepatic functions than desflurane in patients undergoing partial hepatectomy during the first six postoperative days.

ARTICLE HISTORY
Received 30 January 2023
Revised 3 March 2023
Accepted 8 March 2023

1. Background

Hepatectomy is commonly used in patients suffering from focal hepatic pathology like focal metastatic lesion, hepatocellular carcinoma, hepatic hemangioma, and other liver diseases. The liver resection causes transient changes in metabolic function, hemostasis, and, possibly, the pharmacokinetics and pharmacodynamics of drugs used. Currently, the most commonly used routine technique is inflow occlusion by clamping the portal triad (Pringle's maneuver) during liver transection to minimize blood loss [1]. Nevertheless, the Pringle technique causes ischemic injury in the remaining liver which may be vulnerable to a brief cessation of blood supply [2].

The mechanisms underlying ischemia-reperfusion injury (IRI) in the liver are quite complicated. It is linked to a number of events, including the Kupffer cell activation, neutrophil infiltration and rise in adhesion molecule levels, release of cytokines, and injury to the hepatocytes [3]. More evidence suggests that reactive oxygen species produced in excess during the initial phase of reperfusion act as a signaling molecule, causing the release of endogenous damage-associated molecules that cause hepatocellular injury [4].

Anesthetic drug advancements, surgical new techniques, and a deep understanding of pathophysiological techniques have enabled liver resections to be transformed into safe surgeries with low morbidity and mortality in recent decades [5].

Propofol (2,6-diisopropylphenol) is a commonly used anesthetic drug which is metabolized in the liver mainly through the cytochrome P450 system and glucuronidation [4]. In addition to its multiple anesthetic benefits, propofol has many non-anesthetic properties. One of them is increasing antioxidant capacity in various tissues. [6].

Dexmedetomidine is a potent and selective α 2-adrenoceptor agonist. It improves perioperative stability of hemodynamics and has anesthetic sparing properties [7]. Dexmedetomidine has been shown to protect against IRI of the brain, heart, testis, kidney,

CONTACT Ola A. Saad Ali Lashin ola.lashin@med.asu.edu.eg Department of Anesthesiology, Intensive care and Pain Management, Faculty of Medicine, Ain-Shams University Abbassia, Cairo 11591, Egypt

and, most recently, the liver both in vivo and in vitro. [8].

Desflurane is a fluorinated methyl ethyl ether that is used to maintain general anesthesia (GA). It has the quickest onset and offset when compared to other volatile anesthetic drugs [9]. Many recent studies have suggested that administering desflurane has been shown to provide early hepatoprotection against IRI. However, the exact molecular mechanisms are still unknown. [10].

This study aimed to compare the effects of intravenous infusion of propofol/dexmedetomidine versus inhaled desflurane on hepatocellular functions in patients undergoing partial hepatectomy. Serum concentrations of aspartate aminotransferase (AST) and alanine aminotransferase (ALT), which indicate the degree of liver damage, and serum albumin, total and direct serum bilirubin, prothrombin time (PT), and international normalized ratio (INR), which indicate liver function, were compared before anesthesia and at days 1, 3, and 6 after surgery.

1.1. Trial registration and ethical committee approval

The study was a randomized prospective comparative study that was conducted at Ain Shams University Hospitals. It was approved by the research ethics committee in the Faculty of Medicine, Ain Shams University (FMASU M D 209/2020). The study was registered with trial registration and ethical approval: clinical trials (www.clinicaltrials.gov) database ID no (NCT05246371).

2. Methods and measurements

The study was a randomized prospective comparative study that was carried out from November 2020 to November 2022 at Ain Shams University Hospitals.

3. Randomization and patient allocation

Thirty patients over the age of 18 years old with the American Society of Anesthesiologists physical status II, Child–Pugh classification A to B, and patients who were scheduled for more than one segment hepatectomy were included in the study. Both sexes were included in the study. A computer-generated random number table was used to divide the patients into two equal groups, each group had 15 patients, namely group A and group B.

Group A: Fifteen patients received total intravenous anesthesia (TIVA) for the maintenance of GA using a combination of propofol and dexmedetomidine.

Group B: Fifteen patients received the maintenance of GA using desflurane.

3.1. Exclusion criteria

(a) Patients with Child–Pugh classification C.
(b) Patients <18 years old.
(c) Scheduled liver resection without the need for inflow occlusion (Pringle's maneuver).
(d) Hypersensitivity to any of the above-mentioned drugs.
(e) Previous liver resection in preparation for donation.
(f) Patients who underwent previous ablation treatments (radiofrequency ablation or cryosurgery).

4. Sample size calculation

The sample size was calculated using the STATA program, with the alpha error set to 5%. The outcome of a previous study done by Fayed et al. [11] demonstrated that the mean ALT in the dexmedetomidine group was 4.81 ± 4.87 compared to 97.5 ± 11.7 in the control group. Based on this, 15 cases per group (30 total) will achieve 100% power to detect the observed difference between groups in ALT.

4.1. Patients' interventions and management

Preoperatively, all patients were evaluated and told to fast for 8 h for solids and 2 h for clear fluids. Upon arrival at the operating room, a ringer solution was infused at a rate of 10 ml/kg/h after intravenous access was established. For sedation, the patient was given 2 mg of midazolam intravenously. Intraoperative monitoring included noninvasive blood pressure, electrocardiogram (ECG), and arterial oxygen saturation. In the propofol dexmedetomidine group (group A), induction of GA started using 3 mcg/kg fentanyl, followed by propofol 2 mg/kg, IV loading dose of dexmedetomidine 1 mcg/kg over 10 min, and 0. 5 mg/kg atracurium. In the desflurane group (group B), induction of GA started using 3 mcg/kg fentanyl, followed by thiopental sodium (5 mg/kg) and 0.5 mg/kg atracurium.

After tracheal intubation, all patients of both groups were ventilated at 6–8 ml/kg tidal volume to keep end-tidal CO_2 levels around 35 mmHg. A central venous line was placed in the internal jugular vein, and an invasive arterial line was placed in the radial artery. Patients were monitored for invasive blood pressure, blood oxygen saturation, ECG, end-tidal CO_2, arterial blood gases, and urine output. In group A, anesthesia was maintained by infusing propofol at a rate of 0.1–0.2 mg/kg/min and dexmedetomidine infusion of maintenance dose at a rate of 0.6 mcg/kg/h. Ventilation was maintained by an oxygen-air gas mixture to achieve FiO_2 0.5 and a flow of 2 L/min in a closed respiratory system. In group B, anesthesia was maintained by

desflurane inhalation with vaporizer set between 4 and 10 vol% in FiO_2 0.5 and a flow of 2 L/min in a closed respiratory system. Fentanyl was infused into both groups at a rate of 1–2 mcg/kg/h, and atracurium was infused at a rate of 0.3–0.6 mg/kg/h.

Under the supervision of an experienced hepatobiliary surgery team, surgical procedures were carried out in a standardized manner. Each patient was followed for the first six post-operative days.

5. Data recording

- Primary outcome: The study's goal was to compare serum concentrations of AST and ALT indicating the extent of liver damage, serum albumin, total and direct serum bilirubin, PT, and INR as markers of liver function before and at days 1, 3, and 6 after surgery.
- Secondary outcome: Comparing intraoperative vital data recorded every hour throughout the procedure in both groups.

5.1. Statistical methods

The Statistical Package for Social Science version 22.0 was used to analyze the data. When indicated, quantitative data were expressed as the mean standard deviation (SD) or the median interquartile range. Qualitative data were expressed as percentage and frequency. The following tests were carried out: the chi-squared (X^2) test of significance was used to compare proportions between two qualitative parameters and the independent-samples *t*-test of significance was used to compare between two means. The confidence interval was set to 95%, and the acceptable margin of error was set to 5%.

6. Results

The study's main finding is that Group A had significantly lower ALT and AST levels than group B at days 1, 3, and 6 postoperatively ($P < 0.001$). Similarly, at days 1, 3, and 6, total bilirubin, direct bilirubin, PT, and INR were significantly lower in group A compared to group B ($P < 0.05$). Serum albumin was significantly higher in group A than in group B at days 3 and 6 postoperatively ($P < 0.005$) (Tables 3 and 4).

Demographic information for both groups was comparable (Table 1).

Table 2 shows that the duration of surgery and ischemia for both groups were comparable.

Group A had significant lower MAP and HR values than group B during the period of 1–5 h anesthesia and recovery ($P < 0.001$) (Figures 1 and 2).

ALT levels in group A were 224.27 ± 29.7 U/L, 144.47 ± 24.1 U/L, and 33.73 ± 11.0 U/L compared to 318.20 ± 52.5 U/L, 226.73 ± 54.4 U/L, and 58.40 ± 13.8 U/L in group B at 1, 3, and 6 days, respectively, indicating significant lower ALT values in group A compared to group B ($P < 0.001$). Similarly, AST levels in group A were 265.60 ± 22.3 U/L, 170.87 ± 23.2 U/L, and 40.00 ± 13.0 U/L compared to 349.27 ± 56.1 U/L, 238.00 ± 38.2 U/L, and 55.33 ± 18.8 U/L in group B at 1, 3, and 6 days, respectively, indicating significant lower AST values in group A compared to group B ($P < 0.001$) (Table 3).

Serum albumin was significantly higher in group A (3.58 ± 0.2 g/dL and 3.36 ± 0.2 g/dL) than group B (3.36 + 0.2 g/dL and 3.43 + 0.2 g/dL) at days 3 and 6, respectively ($P < 0.005$) (Table 4).

Table 4 also shows that at days 1, 3, and 6, total bilirubin, direct bilirubin, PT, and INR were significantly lower in group A than group B ($P < 0.05$)

7. Discussion

This study's main finding shows that propofol/dexmedetomidine as a technique for the maintenance of anesthesia resulted in less hepatocellular injury and better hepatic function than desflurane in patients undergoing partial hepatectomy during the first six postoperative days.

Many strategies for reducing IRI during liver resection have been developed. Ischemic preconditioning and intermittent portal triad clamping were the two most commonly used clinical techniques [1,12]. Both techniques prolong the operation and expose the remaining liver tissue to ischemia and IRI. As a result, developing a pharmacological strategy to protect the liver during hepatectomy became critical.

Table 1. Demographic data.

Demographic data		Group A (*n*=15)	Group B (*n*=15)	*P*-value
Age (years)		46.20 ± 13.2	49.93 ± 13.6	0.45
BMI (Kg/m**2**)		28.59 ± 4.7	27.47 ± 3.3	0.45
ASA	I	6 (40%)	7 (46.7%)	0.72
	II	9 (60%)	8 (53.3%)	
Sex	Male	7 (46.7%)	8 (53.3%)	0.72
	Female	8 (53.3%)	7 (46.7%)	

Note: Data are presented as mean ± SD, % = percentage, X^2= chi-squared test, A = TIVA group, B = desflurane group, BMI = body mass index, ASA = American Society of Anesthesiologists.

Table 2. Comparison of groups in terms of surgery duration and ischemia time.

Surgery data	Group A (n=15)	Group B (n=15)	P-value
Duration of surgery (min)	308.67 ± 19.9	314.33 ± 20.9	0.45
Ischemic time (min)	13.60 ± 1.2	13.27 ± 1.3	0.48

Note: Data are presented as mean ± SD, A = TIVA group, B = desflurane group.

Table 3. Comparison of AST and ALT levels between groups.

Postoperative lab data	Group A (n=15)	Group B (n=15)	P-value
ALT BL (U/L)	25.07 ± 47.3	37.80 ± 67.9	0.56
ALT 1 (U/L)	224.27 ± 29.7	318.20 ± 52.5	<0.001*
ALT 3 (U/L)	144.47 ± 24.1	226.73 ± 54.4	<0.001*
ALT 6 (U/L)	33.73 ± 11.0	58.40 ± 13.8	<0.001*
AST BL (U/L)	22.80 ± 13.3	47.27 ± 72.6	0.21
AST 1 (U/L)	265.60 ± 22.3	349.27 ± 56.1	<0.001*
AST 3 (U/L)	170.87 ± 23.2	238.00 ± 38.2	<0.001*
AST 6 (U/L)	40.00 ± 13.0	55.33 ± 18.8	0.01*

Note: Data are presented as mean ± SD, A = TIVA group, B = desflurane group, ALT = alanine aminotransferase, AST= aspartate aminotransferase, BL= baseline, * = significant difference.

Recently, several studies have been conducted to evaluate the effects of different anesthetic drugs on liver function. Propofol was discovered to boost the antioxidant capacity of many organs [13]. Furthermore, recent research suggests that propofol plays a role in the various organ protection during acute injury through its antioxidant and anti-inflammatory properties [14].

Dexmedetomidine was discovered to be beneficial to liver tissues during sepsis. Numerous studies in recent years have demonstrated dexmedetomidine's hepatoprotective action against IRI noticed in patients undergoing hepatectomy [15].

Desflurane's solubility in blood is low, which results in quick onset and offset with minimal metabolism. In clinical practice, desflurane is an attractive maintenance anesthetic in hepatic patients. Many recent studies have suggested that administering desflurane may offer early protection against IRI. However, the underlying molecular mechanisms remain not fully understood [10].

During inflow occlusion using Pringle's maneuver, the liver is subjected to IRI, which is divided into two stages. The first stage begins 2 hafter reperfusion and is characterized by inflammatory response and oxidant stress induced by the Kupffer cell, which results in acute injury to hepatocytes. The second stage appears 6 h or more following reperfusion and is attributed mainly to neutrophil recruitment-induced oxidants and protease release, which causes hepatocyte damage to progress [16]. We planned the observation time points based on the changes in biochemical markers following hepatic resection in the study done by Siu and his colleagues [17].

Our study showed that the propofol dexmedetomidine combination seemed to exert a protective effect against post-hepatectomy hepatocellular injury compared to desflurane as evidenced by significantly lower AST and ALT values in comparison to the desflurane group. Furthermore, total and direct bilirubin, PT, and INR showed significantly lower values in the propofol dexmedetomidine group in comparison to the desflurane group. Albumin levels showed significantly higher values in the propofol dexmedetomidine group in comparison to the desflurane group in days 3 and 6 post-operatively.

In accordance with our findings, Wu and his colleagues (2019) [18] who investigated the effect of propofol versus desflurane on IRI-induced inflammatory response in liver transplant recipients revealed that propofol-based TIVA showed cytoprotective properties and provided attenuated inflammatory response,

Table 4. Comparison between groups as regards serum albumin, total and direct bilirubin, PT, and INR.

Postoperative lab data	A group (n=15)	B group (n=15)	P-value
Albumin BL (g/dL)	4.02 ± 0.3	4.20 ± 0.5	0.21
Albumin 1 (g/dL)	3.73 ± 0.2	3.58 ± 0.3	0.15
Albumin 3 (g/dL)	3.58 ± 0.2	3.36 ± 0.2	**0.005***
Albumin 6 (g/dL)	3.69 ± 0.1	3.43 ± 0.2	**<0.001***
Total billirubin BL (mg/dL)	0.75 ± 0.24	0.60 ± 0.27	0.25
Total billirubin 1 (mg/dL)	1.19 ± 0.4	1.89 ± 0.5	**<0.001***
Total billirubin 3 (mg/dL)	1.24 ± 0.2	1.82 ± 0.2	**<0.001***
Total billirubin 6 (mg/dL)	0.87 ± 0.1	1.06 ± 0.2	**0.01***
Direct billirubin BL (mg/dL)	0.44 ± 0.2	0.33 ± 0.2	0.06
Direct billirubin 1 (mg/dL)	0.87 ± 0.3	1.50 ± 0.6	**0.001***
Direct billirubin 3 (mg/dL)	0.73 ± 0.3	1.17 ± 0.2	**<0.001***
Direct billirubin 6 (mg/dL)	0.56 ± 0.1	0.62 ± 0.2	0.30
PT BL (sec)	12.35 ± 1.7	12.20 ± 1.5	0.80
PT 1 (sec)	12.70 ± 1.5	16.80 ± 3.4	**<0.001***
PT 3 (sec)	12.77 ± 1.1	15.03 ± 2.5	**0.003***
PT 6 (sec)	11.80 ± 1.1	11.53 ± 1.5	0.57
INR BL	1.04 ± 0.2	1.08 ± 0.1	0.54
INR 1	1.09 ± 0.1	1.40 ± 0.2	**<0.001***
INR 3	1.09 ± 0.1	1.31 ± 0.2	**<0.001***
INR 6	1.00 ± 0.1	1.04 ± 0.1	0.31

Note: Data are presented as mean ± SD, A = TIVA group, B= desflurane group, PT = Prothrombin time, sec = second, INR = international normalized ratio, BL = baseline, * = significant difference.

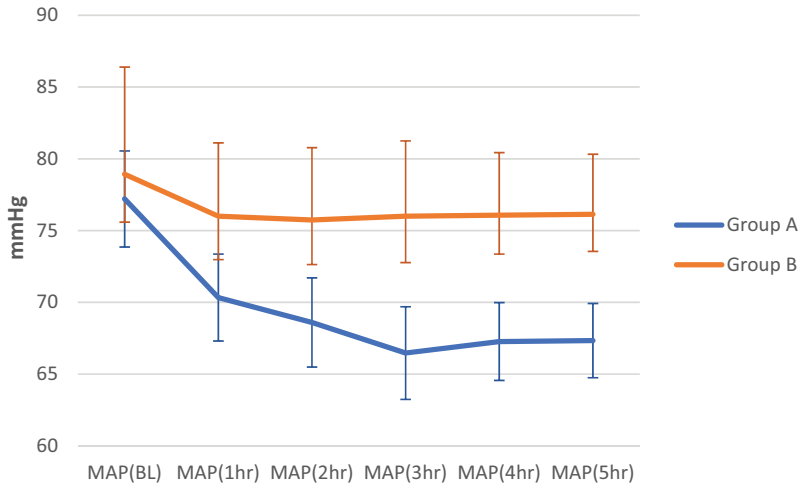

Figure 1. Line graph between groups as regards MAP. Data are presented as mean ± SD, A = TIVA group, B = desflurane group, MAP = mean arterial pressure.

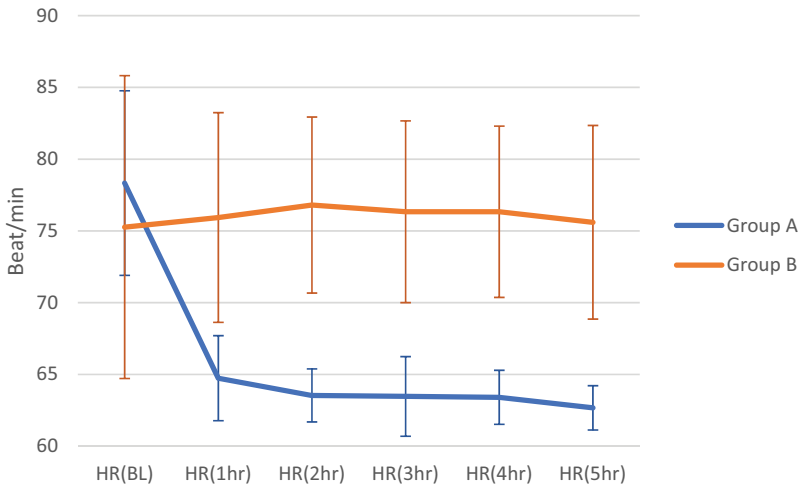

Figure 2. Line graph between groups as regards HR. Data expressed as mean ± SD, A = TIVA group, B = desflurane group, HR = heart rate.

antioxidative stress, improved recovery of graft function, and better microcirculation compared to desflurane. The TIVA group showed a faster return to normal INR and lower ALT values 24 h after liver transplantation.

Another study by Laviolle et al. (2011) [19] studied the effect of anesthesia with propofol compared with desflurane on oxidative stress and hepatic function during and after partial hepatectomy and found that propofol had a protective effect on hepatic damages manifested by a decrease in plasma levels of alpha-glutathione s-transferase (α GST) shortly after vascular unclamping and an improvement in hepatic metabolic function recovery, though there were no differences between both groups in AST and ALT.

On the other hand, in a study conducted by Shin and his colleagues (2019) [20] to compare the effect of propofol intravenous anesthesia with desflurane and desflurane alone on postoperative liver function after living-donor liver transplantation, it was found that there was no improvement in laboratory or surgical outcome after hepatectomy in patients who received propofol compared to patients who received desflurane alone.

Several studies were conducted to study the effect of dexmedetomidine on IRI in patients undergoing hepatectomy. Zhang and colleagues (2020) [21] studied this effect by measuring α GST to detect early damage to liver cells and by measuring AST and ALT. They found that α GST returned to the normal range rapidly and AST and Alt levels were reduced 2 and 24 h after hepatectomy. They showed that dexmedetomidine exerted a protective effect on IRI after hepatectomy.

Human serum albumin is considered to be the most plentiful plasma protein. It represents about 50% of the total plasma proteins (3.5–5 g/l). It is synthesized exclusively by hepatocytes, which allows it to enter the bloodstream without being stored. Normally, 20–30% of hepatocytes only contribute to the production of 9–12 g of albumin per day. As a result, the liver has a substantial functional reserve, so it can increase protein synthesis by 3–4 times when necessary [22].

Although low albumin levels are not a cardinal sign in acute liver injury, hypoalbuminemia was linked to a higher risk of acute liver failure in patients suffering from acute hepatitis A [23]. In the current study, differences in albumin levels were apparent only at days 3 and 6.

In our study, although both surgeons and patients were blinded to group assignment, it was not possible to blind the anesthesiologist to the anesthesia method beside that our results were mainly laboratory which were not subjected to researcher's bias. In group A, the TIVA technique with preset doses of propofol was used due to the unavailability of target controlled infusion (TCI) in our facility. In group B, induction of anesthesia was achieved by thiopental sodium instead of propofol to isolate the effects of desflurane on the liver.

Patients classified as Child–Pugh C cirrhosis were not included in the study as they were considered contraindication for hepatic resection. Patients who performed additional ablation therapies (cryosurgery or radiofrequency ablation) were also excluded for fear that these procedures might have affected the remaining liver tissue functions.

Although total blood loss, total fluid requirements, central venous pressure, pulse pressure variation, and urine output were monitored throughout the procedure, they were not included in the study parameters as we focused on the postoperative liver function. Separating the exact hepatoprotective effects of propofol and dexmedetomidine was not possible in our study design.

Patients treated with propofol/dexmedetomidine showed significantly lower HR and MAP. Other studies referred to similar effects for dexmedetomidine's activation of presynaptic α2-adrenoceptors in both vascular endothelial cells and the central nervous system, which results in vasodilation [24].

Propofol had no advantage over desflurane in lowering MAP [25]. Although we cannot extrapolate these results to our study, however, we may anticipate that the intraoperative hemodynamic differences are mainly due to dexmedetomidine.

8. Conclusion

In conclusion, our results showed that the technique for the maintenance of anesthesia using intravenous infusion of propofol and dexmedetomidine resulting in less derangement in liver functions seems favorable in the early postoperative period after hepatectomy; however, its impact on the final surgical outcome is not known from this study.

Acknowledgments

We agree that all copyright ownership is transferable to the *Egyptian journal of Anesthesia* when the manuscript is accepted for publication.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

No funds, sponsorship, or financial support to be disclosed.

ORCID

Ola A. Saad Ali Lashin http://orcid.org/0000-0002-6966-7386

Authors' contributions

O.A.L. designed the study, revised the literature, performed the analysis, followed up the patients, documented the changes in the desired outcomes, and wrote the manuscript. H.M.E. designed the study, performed the analysis, and wrote and critically revised the manuscript. S.M.T. revised the literature, performed the analysis, and critically reviewed the manuscript. M.M.G. revised the feasibility of the surgical intervention for proper patients, followed up the patients, and critically reviewed the manuscript. M.M.R. collected the data, performed the analysis, and critically reviewed the manuscript. All authors approved the final version of the manuscript.

Ethics approval and consent to participate

After approval of the ethical committee in Faculty of Medicine, Ain Shams University (number FMASU M D 209/2020), this interventional prospective study was conducted on 30 patients over 2 years from November 2020 to November 2022. Written informed consent was obtained from patients' legal guardian(s) after explaining the procedure and its potential complications.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

[1] Winbladh A, Björnsson B, Trulsson L, et al. Ischemic preconditioning prior to intermittent Pringle maneuver in liver resections. J Hepatobiliary Pancreat Sci. 2011;19(2):159–170. DOI:10.1007/s00534-011-0402-9

[2] Song JC, Sun YM, Yang LQ, et al. A comparison of liver function after hepatectomy with inflow occlusion between sevoflurane and propofol anesthesia. Anesthesia & Analgesia. 2010;111(4):1036–1041. DOI:10.1213/ANE.0b013e3181effda8

[3] Wu D, Wang J, Wang H, et al. Protective roles of bioactive peptides during ischemia-reperfusion injury: from bench to bedside. Life Sci. 2017;180:83–92.

[4] Zhang Y, Chen Z, Feng N, et al. Protective effect of propofol preconditioning on ischemia-reperfusion injury in human hepatocyte. J Thoracic Dis. 2017;9(3):702–710. DOI:10.21037/jtd.2017.02.80

[5] Li Z, Sun, Y, Wu, F. Controlled low central venous pressure reduces blood loss and transfusion requirements in hepatectomy. World J Gastroenterol. 2014;20 (1):303. DOI:10.3748/wjg.v20.i1.303
[6] Yuzbasioglu MF, Aykas A, Kurutas EB, et al. Protective effects of propofol against ischemia/reperfusion injury in rat kidneys. Ren Fail. 2010;32(5):578–583.
[7] Wang Z, Huang C, Hua Y, et al. Dexmedetomidine reduces intestinal and hepatic injury after hepatectomy with inflow occlusion under general anaesthesia: a randomized controlled trial. Br J Anaesth. 2014;112 (6):1055–1064. DOI:10.1093/bja/aeu132
[8] Pan J, Li X, He Y, et al. Comparison of dexmedetomidine vs. remifentanil combined with sevoflurane during radiofrequency ablation of hepatocellular carcinoma: a randomized controlled trial. Trials. 2019;20(1).
[9] Ronald D, Miller Lars I, Fleisher ELA, et al. Miller's Anesthesia. Elsevier Health Sci. 9th ed. 2014;624.
[10] Mangus R, Kinsella S, Farar, et al. Impact of volatile anesthetic agents on early clinical outcomes in liver transplantation. Transplant Proc. 2018;50 (5):1372–1377. DOI:10.1016/j.transproceed.2018.03.001
[11] Fayed NA, Sayed EI, Saleh SM, et al. Effect of dexmedetomidine on hepatic ischemia-reperfusion injury in the setting of adult living donor liver transplantation. Clin Transplant. 2016;30(4):470–482. DOI:10.1111/ctr.12713
[12] Rodríguez A, Taurà P, Domingo G, et al. Hepatic cytoprotective effect of ischemic and anesthetic preconditioning before liver resection when using intermittent vascular inflow occlusion: a randomized clinical trial. Surgery. 2015;157(2):249–259. DOI:10.1016/j.surg.2014.09.005
[13] Erbas M, Demiraran Y, Ak Yildirim H, et al. Comparison of effects on the oxidant/antioxidant system of sevoflurane, desflurane and propofol infusion during general anesthesia. Braz J Anesthesiol. English 2015;651:68–72. DOI:10.1016/j.bjan.2014.05.002.
[14] Yao W, Luo G, Zhu G, et al. Propofol activation of the Nrf2 pathway is associated with amelioration of acute lung injury in a rat liver transplantation model. Oxid Med Cell Longevity. 2014;2014:1–9.
[15] Taman H, Elhefnawy E. Hepatic protective effect of dexmedetomidine after partial hepatectomy surgery: a prospective controlled study. Anesth Essays and Res. 2019;13(1):132.
[16] Huang YQ, Wen RT, Li XT, et al. The protective effect of dexmedetomidine against Ischemia-reperfusion injury after hepatectomy: a meta-analysis of randomized controlled trials. Front Pharmacol. 2021;12. DOI:10.3389/fphar.2021.747911.
[17] Siu J, McCall J, Connor S. Systematic review of pathophysiological changes following hepatic resection. HPB. 2014;16(5):407–421.
[18] Wu ZF, Lin WL, Lee MS, et al. Propofol vs desflurane on the cytokine, matrix metalloproteinase-9, and heme oxygenase-1 response during living donor liver transplantation. Medicine. 2019;98(48):e18244. DOI:10.1097/MD.0000000000018244
[19] Laviolle B, Basquin C, Aguillon D, et al. Effect of an anesthesia with propofol compared with desflurane on free radical production and liver function after partial hepatectomy. Fundam Clin Pharmacol. 2011;26(6):735–742. DOI:10.1111/j.1472-8206.2011.00958.x
[20] Shin S, Joo DJ, Kim MS, et al. Propofol intravenous anaesthesia with desflurane compared with desflurane alone on postoperative liver function after living-donor liver transplantation. Eur J Anaesthesiol. 2019;36(9):656–666. DOI:10.1097/EJA.0000000000001018
[21] Zhang Y, Liu M, Yang Y, et al. Dexmedetomidine exerts a protective effect on ischemia-reperfusion injury after hepatectomy: a prospective, randomized, controlled study. J Clin Anesth. 2020;61:109631.
[22] Quinlan GJ, Martin GS, Evans TW. Albumin: biochemical properties and therapeutic potential. Hepatology. 2005;41(6):1211–1219.
[23] Jiang AA, Greenwald HS, Sheikh L, et al. Predictors of acute liver failure in patients with acute hepatitis A: an analysis of the 2016–2018 San Diego County hepatitis A outbreak. Open Forum Infect Dis. 2019;6(11).
[24] Colin P, Hannivoort L, Eleveld D, et al. Dexmedetomidine pharmacodynamics in healthy volunteers: 2. Haemodynamic profile. Br J Anaesth. 2017;119(2):211–220. DOI:10.1093/bja/aex086
[25] Gollapudy S, Gashkoff DA, Poetker D, et al. Surgical field visualization during functional endoscopic sinus surgery: comparison of propofol- vs desflurane-based anesthesia. Otolaryngol Head Neck Surg. 2020;163 (4):835–842. DOI:10.1177/0194599820921863