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Research Article

Effect of anesthetic choice on ST-segment-defined myocardial ischemia and early postoperative course in monopolar TURP

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ABSTRACT

Objective: This historical cohort, originally collected as a prospective, randomized study was re-analyzed to compare propofol–remifentanyl–based intravenous anesthesia (P-RIA) and sevoflurane-based balanced anesthesia (BA) regarding ST-segment-defined myocardial ischemia and hemodynamic stability in elderly ASA II–III patients with cardiovascular comorbidities undergoing monopolar transurethral resection of the prostate (TURP). As troponin measurements were unavailable, myocardial injury after non-cardiac surgery (MINS) was considered only as a conceptual framework rather than a predefined endpoint.

Methods: Sixty-six patients scheduled for elective monopolar TURP ($n = 33$ per group) were randomized in a single-center, outcome-assessor-blinded design to receive P-RIA or BA. Continuous ST-segment monitoring (leads DII, V5, aVL) was performed from 15 minutes before induction to 15 minutes postoperatively. ECGs were read by a blinded cardiologist, and hemodynamics, electrolytes, and CK-MB/CK were recorded serially.

Results: Baseline demographic and surgical characteristics, as well as overall ischemia incidence and duration, were similar between groups. Blood pressure and heart rate were lower and more stable with P-RIA. At 15 minutes postoperatively, ischemia was less frequent in the P-RIA group than in the BA group (15.2% vs 36.4%; $p = 0.045$), an exploratory finding. CK-MB levels, CK-MB/CK ratios, electrolyte values, and postoperative complications did not differ significantly.

Conclusion: In this elderly, comorbid TURP cohort, P-RIA was associated with a more stable hemodynamic profile and a transiently lower early postoperative ischemia rate, without reducing total perioperative ischemic burden or CK-MB–based myocardial injury. The data are hypothesis-generating and require confirmation in larger troponin-based MINS studies.

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1. Introduction

Transurethral resection of the prostate (TURP) remains one of the principal surgical options for the treat-

ment of symptomatic benign prostatic hyperplasia (BPH) and, with appropriate perioperative optimization, offers an acceptable cardiac risk profile even in elderly patients with cardiovascular comorbidities [1]. How-

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ever, in patients with significant comorbidity or those receiving anticoagulant therapy, minimally invasive techniques such as bipolar TURP and holmium laser enucleation of the prostate (HoLEP) are increasingly recommended because they reduce blood loss, irrigation load, and the risk of TUR syndrome [1–7].

Perioperative cardiac risk assessment has moved beyond traditional symptom- and ECG-based approaches, demonstrating that most myocardial injury after non-cardiac surgery is clinically silent and that elevations in high-sensitivity troponin carry strong prognostic value [8]. Accordingly, contemporary guidelines recommend postoperative troponin surveillance in high-risk patients and advocate integrating the concept of myocardial injury after non-cardiac surgery (MINS) into clinical decision-making algorithms [8–11]. However, because this study was conducted in 2001, high-sensitivity troponin measurements were not available; therefore, MINS was not evaluated as a direct endpoint but was instead used as a conceptual framework to interpret the observed ST-segment changes and CK-MB/CK findings.

The effect of anesthetic technique on myocardial ischemia and hemodynamic stability remains uncertain. Despite the potential cardioprotective properties of volatile agents, recent studies have not demonstrated a clear advantage of sevoflurane–remifentanyl over propofol–remifentanyl, instead emphasizing that hemodynamic stability is the principal determinant of risk [12–14]. In the present study, because nitrous oxide was used in both arms, the propofol–remifentanyl regimen is described as “propofol–remifentanyl–based intravenous anesthesia” rather than classical total intravenous anesthesia (TIVA).

The aim of this study was to compare the effects of propofol–remifentanyl–based intravenous anesthesia and sevoflurane-based balanced anesthesia on ST-segment–defined myocardial ischemia and perioperative hemodynamic stability in elderly ASA II–III monopolar TURP patients with cardiovascular comorbidities. Our hypothesis was that a propofol–remifentanyl–based regimen would provide a more stable hemodynamic profile and thereby modify ischemic patterns. In addition, the ST-segment and hemodynamic findings were planned to be interpreted in light of the MINS literature, not for direct diagnostic purposes, but to offer an interpretative, hypothesis-generating framework.

2. Materials and Methods

2.1. Study design and ethical approval

The study was conducted in accordance with the Declaration of Helsinki after approval by the institutional ethics committee (date: 2001-06-04) as a prospective, randomized, single-center, outcome-assessor-blinded clinical trial. Treatment allocation was known only to the anesthesiologist, whereas patients, surgeons, postoperative clinical assessors, data analysts, and the cardiologist interpreting the ECGs were all blinded to group assignment. Written informed consent was obtained from all participants. Because the study was initiated at a time

when prospective clinical trial registration was not mandatory, no trial registration number is available.

2.2. Patient selection, exclusion criteria and randomization

Between June and November 2001, 80 consecutive male patients aged 50–87 years, classified as ASA II–III and scheduled for elective monopolar TURP due to benign prostatic obstruction, were assessed for eligibility. Fourteen patients were excluded because of missing pre- or postoperative laboratory data ($n = 5$), incomplete postoperative ECG monitoring ($n = 2$), discharge before completion of 24-hour observation ($n = 6$), or withdrawal of consent after preoperative preparation ($n = 1$), leaving 66 patients who completed the protocol and were included in the final analysis. The CONSORT flow diagram of screening, randomization, and analysis is shown in Fig. 1.

Exclusion criteria were severe heart failure, hemodynamically significant valvular heart disease, myocardial infarction within the preceding 6 months, uncontrolled arrhythmia, severe pulmonary/renal/hepatic failure, major conduction disturbances, preoperative hemoglobin < 12 g/dL, age < 50 or > 90 years, and preference for regional anesthesia. Coronary artery disease, hypertension, diabetes mellitus, prior stroke, mild–moderate valvular disease, COPD, obesity, and smoking were recorded as cardiovascular comorbidities but were not exclusion criteria.

Cardiac risk assessment was based on the ASA physical status classification, the Goldman cardiac risk index, and clinical variables (ejection fraction, functional capacity, arrhythmias, and comorbidities). As most patients were elderly with cardiovascular comorbidities and fell into the low–intermediate Goldman risk categories, the cohort was defined as “elderly ASA II–III monopolar TURP patients with cardiovascular comorbidities.”

Patients who provided written informed consent were randomized in a 1:1 ratio to receive either sevoflurane-based balanced anesthesia (BA, $n = 33$) or propofol–remifentanyl–based intravenous anesthesia (P-RIA, $n = 33$). Randomization was performed by a researcher independent of anesthesia management using a computer-generated allocation list concealed in sequentially numbered, opaque, sealed envelopes. Group assignment was disclosed only to the anesthesiologist, while all other clinical and assessment teams remained blinded.

For all randomized patients, demographic data, ASA class, Goldman index, preoperative ejection fraction, surgical and anesthesia durations, calculated irrigation fluid absorption, and resected prostate weight were recorded prospectively.

2.3. Anesthesia protocol

All patients were monitored using standard modalities, including heart rate, noninvasive arterial blood pressure, SpO₂, ET-CO₂, and five-lead ECG (DII, V5, aVL). Premedication consisted of 0.03 mg/kg IV midazolam and 7 ml/kg 0.9% NaCl, followed by 2–3 minutes of preoxygenation with 100% oxygen. Induction was achieved

in both groups with remifentanyl (0.5–1 µg/kg), combined with etomidate (0.15–0.25 mg/kg) in the BA group and propofol (1–2 mg/kg) in the P-RIA group; all patients received vecuronium 0.1 mg/kg to facilitate tracheal intubation. Anesthesia was maintained with 1–3%

sevoflurane in the BA group and with remifentanyl (0.1–0.5 µg/kg/min) plus propofol (3–6 mg/kg/h) in the P-RIA group, using a 66% N₂O/33% O₂ gas mixture in both groups; supplemental vecuronium (0.02 mg/kg) was given as needed.

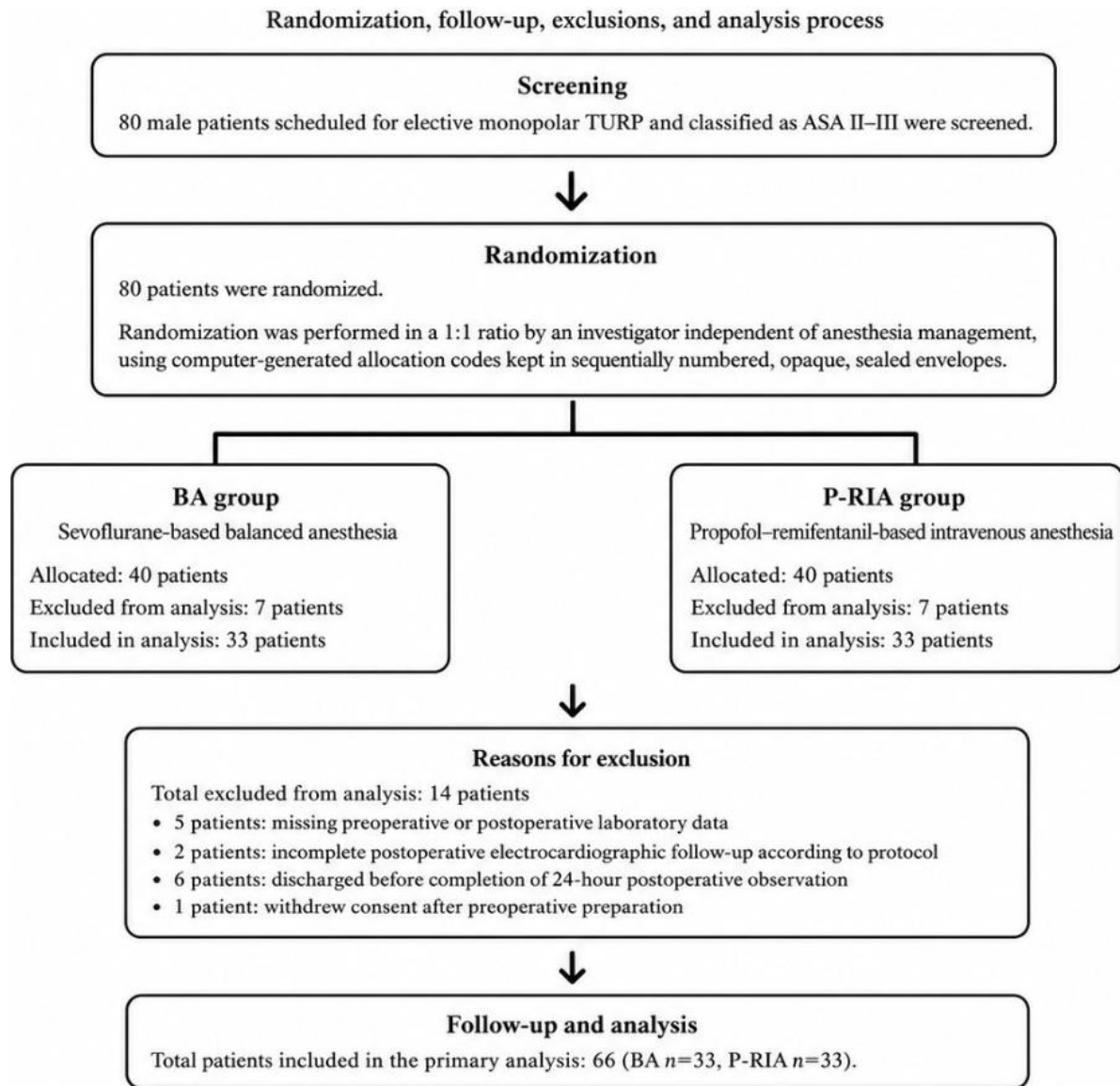


Fig. 1. This CONSORT flow diagram shows the screening, randomization, group allocation, exclusion from analysis, and final analysis process, assuming that randomization occurred before post-randomization exclusions in ASA II–III patients scheduled for elective monopolar TURP.

Depth of anesthesia was assessed clinically rather than with processed electroencephalography (EEG) monitoring, and hypnotic/analgesic doses were titrated accordingly. Hypotension (systolic blood pressure < 85 mmHg) or bradycardia (heart rate < 50 beats/min) triggered a stepwise response: anesthetic dose reduction and optimization of intravascular volume as the first-line measure, followed by an increased crystalloid infusion rate if the response was insufficient. As a result of this stepwise approach, no patient required a vasopressor for persistent hypotension or atropine (0.01 mg/kg) for bradycardia; these episodes were therefore not quantified as a separate variable.

Postoperative analgesia was standardized with intramuscular tramadol (1–1.5 mg/kg) given 10–20 minutes

before the end of surgery. Because pain scores were not recorded systematically, the relationship between early postoperative pain and sympathetic responses could not be analyzed. Neuromuscular block was reversed with neostigmine (0.02–0.08 mg/kg) plus atropine (0.01 mg/kg); anesthetic agents were discontinued, patients were extubated, and then transferred to the recovery unit with 100% oxygen.

2.4. Surgical technique and fluid absorption

All TURP procedures were performed in the lithotomy position using a standard resectoscope and 1.5% glycine irrigation; the irrigation bags were positioned approximately 60 cm above the level of the pubic sym-

physis. Surgical, resection, and anesthesia durations, as well as the total volume of irrigation fluid administered and the calculated volume absorbed, were recorded prospectively. Irrigation fluid absorption was estimated using a standard formula based on the change in serum sodium concentration and the initial extracellular fluid volume (ECF, assumed to be 20% of body weight) [15].

$$\text{Volume Absorbed} = \left(\frac{\text{Preoperative serum Na}}{\text{Postoperative serum Na}} \cdot \text{ECF} \right) - \text{ECF} \quad (1)$$

During the intraoperative period, crystalloid solutions were infused at a rate of 4–6 ml/kg/h, and both the total fluid volume administered and urine output were recorded. Transfusion requirements were standardized according to predefined hemoglobin targets, with thresholds of ≥ 12 g/dL preoperatively and ≥ 10 g/dL postoperatively.

2.5. Definition of myocardial ischemia and ECG monitoring

In all patients, left ventricular ejection fraction was assessed by transthoracic echocardiography within 24 hours before surgery, and myocardial ischemia screening was performed with a 12-lead ECG; all tracings were reviewed by a blinded cardiologist. During intraoperative monitoring, continuous ST-segment surveillance was carried out in leads DII, V5, and aVL from 15 minutes before induction until 15 minutes after the end of surgery. Myocardial ischemia was defined as ≥ 1 mm ST-segment depression or ≥ 2 mm ST-segment elevation lasting at least 1 minute, measured 80 ms after the J point.

In the postoperative period, 12-lead ECGs were repeated at 6 and 24 hours, and all recordings were evaluated by the same cardiologist. For each patient, ischemia incidence, total ischemia duration, number of ischemic episodes, and maximal ST deviation were calculated. The primary endpoint was the overall incidence of perioperative ST-segment-defined myocardial ischemia, defined as the occurrence of at least one ischemic episode during the predefined monitoring period. Secondary endpoints included total ischemia duration, number of ischemic episodes, maximal ST-segment deviation, and hemodynamic variables (systolic and mean arterial pressure and heart rate) measured at predefined intraoperative and early postoperative time points. Exploratory analyses focused particularly on the frequency of ischemia at the early postoperative 15th minute.

2.6. Clinical and laboratory variables

In all patients, baseline laboratory evaluation included complete blood count (Hb, Hct), cardiac biochemistry (CK, CK-MB), serum electrolytes (Na, K), and arterial blood gas analysis; these measurements were repeated at 0 and 24 hours postoperatively. The maximum decrease in Hb/Hct was calculated as the difference between the preoperative value and the lowest postoperative value. Changes in CK-MB concentration and the CK-MB/CK ratio were assessed as biochemical indicators of myocardial injury, with upper reference limits defined as 25 IU/L for CK-MB and 5% for the CK-MB/CK

ratio.

The presence of hypertension, diabetes, COPD, atrial fibrillation, smoking, heart failure, previous stroke, exercise limitation, mild valvular heart disease, coronary artery disease, and obesity was recorded to derive the overall comorbidity burden. During the postoperative period, atrial fibrillation, ischemic stroke, TUR syndrome, chest pain, ventricular premature beats, pulmonary thromboembolism, electrolyte disturbances, and severe anemia (Hb < 9 g/dL) were prospectively monitored.

2.7. Hemodynamic monitoring and subgroup analysis by myocardial ischemia

Systolic and mean arterial pressure and heart rate were recorded at predefined standard time points (baseline, after premedication, during induction-intubation, after positioning, at the start of resection, as an intraoperative mean value, before and after reversal, at the end of anesthesia, at extubation, and immediately before transfer to the recovery unit). Temporal changes were analyzed both within and between groups.

In addition, patients were stratified according to the occurrence of myocardial ischemia (ischemia: $n = 29$; no ischemia: $n = 37$), and these subgroups were compared with respect to demographic characteristics, cardiac risk scores, overall comorbidity burden, perioperative variables, irrigation volume, laboratory findings, and postoperative complications.

2.8. Sample size calculation

The sample size was prospectively calculated based on the primary hypothesis that propofol-remifentanyl-based intravenous anesthesia (P-RIA) would reduce the incidence of perioperative ST-segment-defined myocardial ischemia compared with sevoflurane-based balanced anesthesia (BA). In high-risk TURP series, the incidence of ischemia under volatile anesthesia has been reported to be approximately 40–50%, and for this study a reduction from 50% to 15% (an absolute decrease of 35 percentage points) was considered clinically meaningful.

Assuming a two-sided comparison of two independent proportions with $\alpha = 0.05$ and 80% power, the required sample size was calculated as at least 30 patients per group. To compensate for potential dropouts and protocol deviations, the target sample size was increased to 33 patients in each arm, yielding a total of 66 randomized patients.

2.9. Statistical analysis

All statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA), and a two-sided p value < 0.05 was considered the threshold for statistical significance. Given the exploratory nature of the study and the relatively small sample size, no formal adjustment for multiple comparisons was applied; p values were interpreted descriptively, with the risk of false-positive findings due to multiple testing taken into account.

Continuous variables are presented as mean $\pm$ standard deviation, and categorical variables as counts and percentages. For comparisons between two independent groups, the Student t test was used for normally distributed continuous data and the Mann–Whitney U test for non-normally distributed data; categorical var-

iables were analyzed using the chi-square test or Fisher's exact test, as appropriate. Repeated-measures analysis of variance (ANOVA) was applied to assess time-dependent changes, and, when a significant main effect was detected, suitable post-hoc tests were conducted.

Table 1. Demographic, preoperative cardiac risk, comorbidities and postoperative complications in the balanced anesthesia and P-RIA groups.

	BA (n = 33)	P-RIA (n = 33)	p
Age (years)	67.7 $\pm$ 8.5	69.5 $\pm$ 5.8	0.286
Weight (kg)	70.3 $\pm$ 13.2	70.9 $\pm$ 15.2	0.856
Height (m)	1.64 $\pm$ 0.07	1.61 $\pm$ 0.06	0.057
BMI (kg/m ²)	25.97 $\pm$ 4.2	27.21 $\pm$ 5.2	0.349
ASA II / III	25 (75.8) / 8 (24.2)	23 (69.7) / 10 (30.3)	0.580
Goldman cardiac risk index – Low / intermediate / high	22 (66.7) / 8 (24.2) / 3 (9.1)	18 (54.5) / 11 (33.3) / 4 (12.1)	0.602
Resection time (min)	46.94 $\pm$ 20.1	47.27 $\pm$ 18.1	0.700
Anesthesia time (min)	55.91 $\pm$ 21.3	57.21 $\pm$ 19.3	0.686
Total glycine used (L)	14.73 $\pm$ 6.02	15.99 $\pm$ 6.6	0.302
Glycine absorbed (L)	0.62 $\pm$ 0.6	1.1 $\pm$ 0.9	0.041
Resected prostate weight (g)	18.85 $\pm$ 13.1	21.91 $\pm$ 14.6	0.267
Preoperative ejection fraction (%)	65.7 $\pm$ 5.8	60.3 $\pm$ 11.2	0.034
Myocardial ischemia incidence, n (%)	16 (48.5)	13 (39.4)	0.457
Comorbidities			
Number of comorbidities	2.27 $\pm$ 1.15	2.76 $\pm$ 1.82	0.301
Hypertension	14 (42.4)	10 (30.3)	0.306
Diabetes mellitus	4 (12.1)	4 (12.1)	1
COPD	13 (39.4)	16 (48.5)	0.457
Atrial fibrillation	1 (3)	2 (6.1)	0.555
Smoking history	19 (57.6)	18 (54.5)	0.804
Heart failure	6 (18.2)	7 (21.2)	0.757
Previous stroke	1 (3)	5 (15)	0.087
Exercise limitation	5 (15.2)	10 (30.3)	0.142
Mitral regurgitation (mild)	3 (9.1)	7 (21.2)	0.170
Aortic regurgitation (mild)	1 (3)	3 (9.1)	0.302
Coronary artery disease	5 (15.2)	2 (6.1)	0.230
Obesity	6 (18.2)	8 (24.2)	0.547
Complications			
Atrial fibrillation	1 (3)	0 (0)	0.500
Ischemic stroke	1 (3)	1 (3)	1
TUR syndrome	0 (0)	2 (6.1)	0.246
Chest pain	1 (3)	0 (0)	0.500
Ventricular premature beats	0 (0)	1 (3)	0.500
Pulmonary thromboembolism	0 (0)	1 (3)	0.500
Hyponatremia			
Mild	11 (33.3)	7 (21.2)	0.269
Moderate	3 (9.1)	9 (27.3)	0.056
Severe	4 (12.1)	6 (18.2)	0.492
Hypokalemia	14 (42.4)	17 (51.5)	0.459
Anemia (Hb < 9 g/dL)	8 (24.2)	7 (21.2)	0.769

Abbreviations: BA, balanced anesthesia; P-RIA, propofol–remifentanyl-based intravenous anesthesia, BMI, body mass index; ASA, American Society of Anesthesiologists, COPD, chronic obstructive pulmonary disease; TUR, transurethral resection of the prostate. Values are presented as mean $\pm$ SD or n (%). Statistical significance was defined as $p < 0.05$.

An additional post hoc analysis was performed to evaluate the statistical power for the primary endpoint, the overall incidence of perioperative ST-segment-defined myocardial ischemia. The ischemia incidence was 48.5% in the BA group and 39.4% in the P-RIA group (absolute difference $\approx$ 9.1%; $n = 33$ per group). Using these observed proportions and a two-sided comparison of two independent proportions at $\alpha = 0.05$ with a normal

approximation, the post hoc power was estimated at approximately 12%. Because this observed effect size was much smaller than the prospectively assumed absolute risk reduction of 35%, the study was considered underpowered to detect small-to-moderate differences in global ischemic burden or rare cardiac events; accordingly, the findings are interpreted as exploratory and hypothesis-generating rather than confirmatory.

Table 2. Perioperative systolic and mean arterial pressure and heart rate profiles in the balanced anesthesia and P-RIA groups.

	BA ($n = 33$)	P-RIA ($n = 33$)	Between-group p	Within BA p	Within P-RIA p
Systolic arterial pressure (mmHg)					
Preoperative	153.03 $\pm$ 20.3	155.33 $\pm$ 24.7	0.680		
After premedication	139.88 $\pm$ 21.3	138.82 $\pm$ 21	0.839	0.001	0.001
After induction	114.76 $\pm$ 22.3	85.24 $\pm$ 20.7	0.001	0.001	0.001
After intubation	168.18 $\pm$ 35	122.94 $\pm$ 34.9	0.001	0.019	0.001
After lithotomy	158.88 $\pm$ 31.1	123.27 $\pm$ 28.3	0.001	0.269	0.001
At start of resection	144.94 $\pm$ 35.3	113.09 $\pm$ 27.2	0.001	0.125	0.001
Intraoperative mean	127.45 $\pm$ 24.7	108.15 $\pm$ 24.1	0.002	0.001	0.001
Pre-reversal	121.09 $\pm$ 29	106.85 $\pm$ 24.1	0.034	0.001	0.001
Post-reversal	126.18 $\pm$ 33.3	106.52 $\pm$ 23.2	0.007	0.001	0.001
At end of anesthesia	124.42 $\pm$ 29.3	105.85 $\pm$ 27.5	0.010	0.001	0.001
Supine	137.42 $\pm$ 33.1	118.64 $\pm$ 30.8	0.020	0.008	0.001
After extubation	163.33 $\pm$ 33.2	140 $\pm$ 28.7	0.003	0.052	0.007
Before recovery	161.33 $\pm$ 28.5	141.24 $\pm$ 26.6	0.004	0.057	0.007
Mean arterial pressure (mmHg)					
Preoperative	110.51 $\pm$ 11.8	112.87 $\pm$ 13.5	0.452		
After premedication	100.14 $\pm$ 12.1	101.28 $\pm$ 12.1	0.703	0.001	0.001
After induction	85.18 $\pm$ 14.5	65.1 $\pm$ 16.4	0.001	0.001	0.001
After intubation	125.66 $\pm$ 23.70	95.36 $\pm$ 23.4	0.001	0.001	0.001
After lithotomy	119.46 $\pm$ 25.6	93.43 $\pm$ 17.9	0.001	0.04	0.001
At start of resection	110.64 $\pm$ 26.5	87.09 $\pm$ 19.2	0.001	0.973	0.001
Intraoperative mean	97.96 $\pm$ 17.2	82.09 $\pm$ 16.6	0.001	0.001	0.001
Pre-reversal	92.93 $\pm$ 20.6	81.09 $\pm$ 17.9	0.015	0.001	0.001
Post-reversal	97.68 $\pm$ 23.00	82.36 $\pm$ 17.9	0.004	0.001	0.001
At end of anesthesia	95.82 $\pm$ 19.4	80.98 $\pm$ 20.7	0.004	0.001	0.001
Supine	105.42 $\pm$ 25.6	91.61 $\pm$ 21.9	0.022	0.207	0.001
After extubation	122.40 $\pm$ 24.2	107.78 $\pm$ 21.6	0.012	0.003	0.138
Before recovery	114.79 $\pm$ 18.2	105.53 $\pm$ 19.3	0.049	0.130	0.035
Heart rate (bpm)					
Preoperative	80.88 $\pm$ 14.3	89.42 $\pm$ 17.6	0.034		
After premedication	80.58 $\pm$ 12.9	89.06 $\pm$ 13	0.010	0.760	0.810
After induction	72.45 $\pm$ 12.1	76.82 $\pm$ 11.5	0.138	0.001	0.001
After intubation	87.36 $\pm$ 17.2	87.70 $\pm$ 15.7	0.935	0.020	0.519
After lithotomy	79.91 $\pm$ 15.1	82.91 $\pm$ 14.5	0.414	0.722	0.024
At start of resection	73.42 $\pm$ 15.4	73.70 $\pm$ 13.4	0.939	0.004	0.001
Intraoperative mean	67.48 $\pm$ 11.8	61.39 $\pm$ 10.4	0.030	0.001	0.001
Pre-reversal	64.27 $\pm$ 11.1	56.88 $\pm$ 9.2	0.04	0.001	0.001
Post-reversal	77.97 $\pm$ 13.7	64.09 $\pm$ 13.4	0.001	0.375	0.001
At end of anesthesia	68.24 $\pm$ 13.6	58.73 $\pm$ 11.6	0.003	0.001	0.001
Supine	69.33 $\pm$ 13.8	64.12 $\pm$ 13.1	0.121	0.001	0.001
After extubation	78.55 $\pm$ 12.8	74.88 $\pm$ 14.8	0.286	0.453	0.001
Before recovery	73.15 $\pm$ 13.9	75 $\pm$ 16.3	0.621	0.019	0.001

Abbreviations: BA, balanced anesthesia; P-RIA, propofol-remifentanyl-based intravenous anesthesia; bpm, beats per minute. Values are presented as mean $\pm$ SD. Statistical significance was defined as $p < 0.05$.

3. Results

Baseline demographic characteristics, body size, BMI, ASA class, Goldman score, surgical and anesthesia durations, total glycine volume, resected prostate weight, and overall myocardial ischemia incidence were similar between the BA and P-RIA groups. However, preoperative ejection fraction was higher in the BA group, whereas calculated glycine absorption was greater in the P-RIA group (65.7 ± 5.8 vs $60.3 \pm 11.2\%$ [BA vs P-RIA] and 1.1 ± 0.9 vs 0.62 ± 0.6 L [P-RIA vs BA], respectively; $p = 0.034$, $p = 0.041$). These variables were considered potential confounders, but because the sample size was insufficient for robust multivariable modelling, the results were interpreted in an exploratory manner. No significant between-group differences were observed in overall comorbidity burden or postoperative complications ($p > 0.05$) (Table 1)

Pre- and postoperative Hb/Hct values were compara-

ble, although the maximal decrease was more pronounced in the P-RIA group. In contrast, CK-MB levels, CK-MB/CK ratios, and electrolyte concentrations were similar between groups and remained within normal limits, and no clinically relevant elevation above CK-MB thresholds was detected.

Hemodynamic assessment showed lower and more stable systolic and mean arterial pressures and heart rates in the P-RIA group, a pattern confirmed by repeated-measures analysis (Table 2).

The total incidence of myocardial ischemia, ischemia duration, and number of ischemic episodes did not differ between groups. A higher ischemia rate was observed only at 15 minutes postoperatively in the BA group compared with the P-RIA group (36.4% vs 15.2%), a secondary/exploratory finding that was interpreted cautiously in view of multiple comparisons. Maximal ST-segment deviations and postoperative ECG findings were otherwise similar (Table 3).

Table 3. Myocardial ischemia incidence, duration and timing in the balanced and P-RIA groups.

	BA (n = 33)	P-RIA (n = 33)	p
Myocardial ischemia incidence, n (%)	16 (48.5)	13 (39.4)	0.457
Total ischemia duration (min)	16.09 ± 23.95	11.06 ± 18.43	0.301
Preoperative ischemia duration (min)	1.39 ± 2.83	1.21 ± 2.25	0.778
Intraoperative ischemia duration (min)	12.18 ± 20.38	9.24 ± 15.98	0.714
Postoperative ischemia duration (min)	2.52 ± 4.04	0.76 ± 1.73	0.063
Number of ischemic time points	1.76 ± 2.03	1.39 ± 2.18	0.352
Preoperative ischemia episodes, n (%)	6 (18.2)	8 (24.2)	0.547
Ischemia at induction, n (%)	9 (27.3)	8 (24.2)	0.778
Ischemia at intubation, n (%)	10 (30.3)	8 (24.2)	0.580
Ischemia at extubation, n (%)	10 (30.3)	6 (18.2)	0.251
Ischemia at 15 min postoperatively, n (%)	12 (36.4)	5 (15.2)	0.045
Ischemia on ECG at 6 h postoperatively, n (%)	6 (18.2)	5 (15.2)	0.741
Ischemia on ECG at 24 h postoperatively, n (%)	5 (15.2)	5 (15.2)	1.000
Maximum ST depression amplitude (mm)	1.58 ± 0.29	1.57 ± 0.30	0.987
Maximum ST elevation amplitude (mm)	2.76 ± 0.59	2.72 ± 0.40	0.876

Abbreviations: BA, balanced anesthesia; P-RIA, propofol–remifentanyl-based intravenous anesthesia. Values are presented as mean $\pm$ SD or n (%). Statistical significance was defined as $p < 0.05$.

Among patients who developed ischemia, the proportion with ASA III status was higher, and significant associations were observed with hypertension and heart failure ($p = 0.005$ and $p = 0.007$, respectively) (Table 4). Most ST-segment changes were asymptomatic, and no episodes requiring urgent clinical intervention occurred.

Examination of the temporal distribution of ischemic episodes indicated clustering around airway manipulation and periods of surgical stress in the BA group, whereas in the P-RIA group episodes occurred more often after intubation and during prolonged or intensive resection. In both anesthetic techniques, episodes appeared multifactorial in origin, but hemodynamic fluctuations were attenuated under P-RIA.

4. Discussion

This study is based on a re-evaluation of a historical cohort originally enrolled in a prospective, randomized, outcome-assessor-blinded trial conducted in 2001, with

the findings interpreted in the context of contemporary concepts of perioperative myocardial injury (MINS). At the time, high-sensitivity troponin assays were not available, so the analyses relied on ST-segment changes and CK-MB/CK measurements. The study population consisted of elderly ASA II–III TURP patients with cardiovascular comorbidities, predominantly within the low-intermediate Goldman cardiac risk categories; accordingly, the findings should be viewed as hypothesis-generating for this specific group.

The results indicate that P-RIA was associated with lower and more stable hemodynamic parameters and with a reduced ischemia rate only at the postoperative 15th minute; however, because this difference pertains to a single time point and shows borderline statistical significance ($p = 0.045$), it should not be interpreted as definitive evidence of superiority. The absence of differences in total ischemic burden and CK-MB–based injury is consistent with current literature suggesting that perioperative myocardial damage is driven more by hemodynamic imbalance than by the specific anesthetic agent used [1–3,16–18].

Table 4. Demographic, perioperative and postoperative characteristics in patients with and without myocardial ischemia.

	Myocardial ischemia present (n = 29)	Myocardial ischemia absent (n = 37)	p
Age (years)	68.72 ± 7.9	68.46 ± 6.9	0.885
Weight (kg)	68.69 ± 14.5	72.19 ± 13.8	0.321
Height (m)	1.63 ± 0.1	1.63 ± 0.1	0.941
BMI (kg/m ²)	25.83 ± 5	27.19 ± 4.5	0.251
ASA II / III	17 (58.6) / 12 (41.4)	31 (83.8) / 6 (16.2)	0.023
Goldman cardiac risk index – Low / intermediate / high	14 (48.3) / 11 (37.9) / 4 (13.8)	26 (70.3) / 8 (21.6) / 3 (8.1)	0.193
Resection time (min)	48.45 ± 20.1	46.05 ± 18.2	0.615
Anesthesia time (min)	56.76 ± 20.8	56.41 ± 19.9	0.944
Total glycine used (L)	16.17 ± 6.8	14.72 ± 5.9	0.357
Glycine absorbed (L)	0.76 ± 0.68	0.93 ± 0.89	0.382
Resected prostate weight (g)	20.72 ± 13.3	20.11 ± 14.4	0.859
Preoperative ejection fraction (%)	61.24 ± 10.8	64.38 ± 7.7	0.174
Comorbidities			
Number of comorbidities	2.9 ± 1.8	2.2 ± 1.2	0.890
Hypertension	16 (55.2)	8 (21.6)	0.005
Diabetes mellitus	3 (10.3)	5 (13.5)	0.695
COPD	14 (48.3)	15 (40.5)	0.530
Atrial fibrillation	1 (3.4)	2 (5.4)	0.592
Smoking history	15 (51.7)	22 (59.5)	0.530
Heart failure	10 (34.5)	3 (8.1)	0.007
Previous stroke	2 (6.9)	4 (10.8)	0.583
Exercise limitation	8 (27.6)	7 (18.9)	0.404
Mitral regurgitation (mild)	7 (24.1)	3 (8.1)	0.071
Aortic regurgitation (mild)	3 (10.3)	1 (2.7)	0.197
Coronary artery disease	3 (10.3)	4 (10.8)	0.951
Obesity	6 (20.7)	8 (21.6)	0.927
Complications			
Atrial fibrillation	1 (3.4)	0 (0)	0.439
Ischemic stroke	0 (0)	2 (5.4)	0.500
TUR syndrome	0 (0)	2 (5.4)	0.500
Chest pain	0 (0)	1 (2.7)	0.561
Ventricular premature beats	1 (3.4)	0 (0)	0.439
Pulmonary thromboembolism	0 (0)	1 (2.7)	0.561
Hyponatremia			
Mild	11 (37.9)	7 (18.9)	0.085
Moderate	7 (24.1)	5 (13.5)	0.267
Severe	3 (10.3)	7 (18.9)	0.335
Hypokalemia	15 (51.7)	16 (43.2)	0.493
Anemia (Hb < 9 g/dL)	9 (31)	6 (16.2)	0.154

Abbreviations: BMI, body mass index; ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; TUR, transurethral resection of the prostate. Values are presented as mean ± SD or n (%). Statistical significance was defined as $p < 0.05$.

Although the BA group had a higher baseline ejection fraction—typically indicative of better left ventricular function and cardiac reserve—the overall ST-segment-defined ischemic burden did not differ from that observed with P-RIA. This finding suggests that hemodynamic control may be an important determinant of ischemia independent of ejection fraction. Similarly, the P-RIA group exhibited greater calculated glycine absorption and a more pronounced yet clinically silent decrease

in Hb/Hct, both of which could potentially disturb the myocardial oxygen supply-demand balance; however, no significant differences were detected in total ischemia duration or CK-MB-based myocardial injury despite these factors.

Taken together, these observations indicate that the impact of anesthetic technique and irrigation load is multifactorial and closely intertwined with hemodynamic stability and baseline cardiac reserve. Although

baseline EF was higher in the BA group and glycine absorption was greater in the P-RIA group, neither variable correlated clearly with global ischemia burden, supporting the notion that the observed ischemic and hemodynamic patterns are driven primarily by perioperative blood pressure and heart rate control. Because the sample size was limited, multivariable adjustment including ejection fraction, ASA class, and glycine absorption could not be reliably performed; these variables were therefore treated as potential confounders. Consequently, while the influence of these baseline differences cannot be fully disentangled, the available data nonetheless reinforce the predominant role of hemodynamic stability in determining perioperative cardiovascular outcomes.

These findings, when considered alongside contemporary data indicating that HoLEP, bipolar TURP, and other laser enucleation techniques offer a more favorable safety profile—particularly in elderly BPH patients with substantial comorbidity, with lower blood loss, reduced transfusion requirements, and shorter hospital stays—underscore the need to optimize surgical and anesthetic strategies in parallel. However, the limited availability of detailed data on cardiac-risk subgroups and on comprehensive ischemia monitoring (high-sensitivity troponin, continuous ST-segment surveillance) in HoLEP and related series further highlights the value of the present TURP cohort. The extensive hemodynamic and ST-segment information from this historical dataset, reinterpreted in light of current concepts, provides a useful reference framework that may help inform monitoring strategies in newer surgical techniques [4,5,7,8,19].

The historical nature of this study should be emphasized; its design, data collection period, and outcome definitions differ substantially from contemporary MINS research based on high-sensitivity troponin assays. Consequently, the findings should not be interpreted as directly representative of modern perioperative practice, but rather as a re-evaluation of an ST-segment-based cohort in the light of current concepts.

In both groups, ST-segment changes were similar in magnitude (± 1 –3 mm) and short in duration, suggesting that most episodes were subclinical and predominantly hemodynamic in origin. This is consistent with evidence that perioperative myocardial injury after non-cardiac surgery is frequently asymptomatic and often detected only by elevations in high-sensitivity troponin, despite its strong association with mortality.

Nevertheless, because high-sensitivity troponin was not measured in this study, MINS could not be formally diagnosed and contemporary definitions could not be directly assessed. Although CK-MB and ST-segment findings cannot be mapped one-to-one onto modern MINS criteria, the observed patterns of hypotension, tachycardia, and anemia/hemodilution align closely with the key pathophysiological mechanisms described in the current literature [1,2].

In this context, the findings suggest that P-RIA may attenuate sympathetic activation and hemodynamic fluctuations, particularly in the early postoperative period, and indicate that such an approach should, in contemporary practice, be evaluated in conjunction with systematic high-sensitivity troponin monitoring [1–3,10,16–

18]. Consequently, this study should not be viewed as a direct assessment of MINS but rather as a historical, hypothesis-generating dataset in which ST-segment and CK-MB/CK patterns are interpreted within the framework of mechanisms known to be associated with MINS.

Although a greater volume of glycine absorption was estimated in the P-RIA group, serum sodium and potassium levels were similar between groups. Nevertheless, TURP syndrome was reported in 2 patients in the P-RIA group, and severe hyponatremia was reported in a total of 10 patients across both groups. Thus, similar serum electrolyte levels between groups do not imply the absence of clinically important electrolyte disturbances in individual patients. These findings differ from those of contemporary bipolar TURP and HoLEP series reporting that, with improved irrigation techniques and optimized fluid and electrolyte management, classical TURP syndrome has become rare and hyponatremia is generally mild (Clavien–Dindo grade I–II) [4].

When the more pronounced yet clinically silent decrease in Hb/Hct in the P-RIA group is interpreted alongside MINS literature indicating that anemia and hemodilution can contribute to perioperative myocardial injury but are generally manageable factors, these findings support the notion that the balance between hemodynamic stability and controlled hemodilution plays a key role in cardiac risk management [1,2,5,7,17,18].

In terms of risk profile, the higher prevalence of ASA class III status, hypertension, and heart failure among patients who developed ischemia in the cohort is consistent with the reported determinants of MINS/PMI in large non-cardiac surgical series (Table 4; hypertension $p = 0.005$, heart failure $p = 0.007$). These findings parallel the literature indicating that advanced age and ASA ≥ 3 are independent risk factors, whereas diabetes and COPD make a more limited contribution [17,20]. This concordance supports a reserve-oriented approach that emphasizes the central role of ASA class, blood pressure control, and left ventricular function in cardiac management [12,17,20].

Evidence from noncardiac surgery suggests that differences in hemodynamic responses between sevoflurane- and propofol-based anesthesia do not necessarily translate into differences in major cardiac outcomes. In a randomized trial involving elderly patients with coronary heart disease, Zhang et al. found no significant between-group differences in troponin I or BNP concentrations at the measured time points; however, the 24-hour area under the curve for troponin I was lower and intraoperative hemodynamic stability was better with sevoflurane than with propofol–remifentanyl. Similarly, in their systematic review and meta-analysis, An et al. found no significant differences in postoperative major adverse cardiac events or mortality between sevoflurane and propofol anesthesia, despite lower early postoperative troponin I concentrations and a lower incidence of myocardial ischemia with sevoflurane [21,22].

These findings provide indirect context rather than direct evidence for the comparison of the two regimens used in our TURP population. In the present study, although arterial pressures were higher in the BA group during extubation, the incidence of ischemia was similar between groups. Thus, the observed differences in arte-

rial pressure were not accompanied by a detectable difference in ischemia incidence; however, this observation alone establishes neither cardiac equivalence between the regimens nor a mechanism mediated by modulation of the overall stress response.

Because nitrous oxide was used in both groups, the P-RIA regimen should be described not as classical “total intravenous anesthesia” but as an intravenous anesthesia technique based on propofol–remifentanyl. The hemodynamic advantage of P-RIA rests on serial rather than single measurements; repeated assessments showed lower and less variable systolic and mean arterial pressures, as well as heart rates. This pattern underscores the key role of sustained hemodynamic control in maintaining myocardial oxygen supply–demand balance in high-risk TURP patients.

These findings provide a meaningful framework for re-examining a historical ST-segment and hemodynamic cohort in the light of contemporary MINS concepts; however, the data collection period, the outcome measures employed, and the absence of troponin data limit the extent to which the results can be interpreted as directly representative of a modern perioperative MINS study. Within this context, the study suggests that P-RIA may be associated with a more stable hemodynamic profile in TURP patients at cardiac risk, and further indicates that the lower ST-segment ischemia rate observed at the 15th minute of the early postoperative period is a hypothesis-generating finding that remains uncertain and requires confirmation, given the multiple comparisons and limited sample size.

This prospectively collected, randomized dataset, when re-interpreted from a contemporary MINS perspective, provides a conceptual foundation that may help define target hemodynamic parameters for less invasive BPH procedures such as HoLEP and bipolar TURP [4,5,8,16,19,23]. In this respect, the study can be regarded as a historical data source of reference value for troponin-based MINS research.

This study suggests that a propofol–remifentanyl-based approach may be associated with a more controlled hemodynamic course in elderly ASA II–III TURP patients with cardiovascular comorbidities. However, no clear difference was demonstrated between the two anesthetic techniques in terms of overall ischemic burden or CK-MB-based myocardial injury.

The modest reduction in ischemia observed in the early postoperative period should be regarded as a signal that warrants further investigation rather than as evidence of a definite effect, given the methodological limitations. The absence of troponin data prevents a direct linkage of the results to contemporary MINS definitions. Accordingly, the study should be considered not as a source of findings that can be directly generalized to clinical practice, but as a historical dataset that highlights the importance of perioperative hemodynamic control and provides a foundation for future troponin-based research.

4.1. Limitations

The single-center design and limited sample size leave the study underpowered for rare clinical endpoints

such as MI and mortality, and the absence of troponin measurements raises the possibility that silent injuries meeting contemporary MINS criteria may have been missed. Multiple time-point analyses yielded only one significant finding (at 15 minutes postoperatively), which increases the likelihood of a false-positive result and relegates this outcome to a hypothesis-generating level. Hemodynamic assessment was based on mean values and patterns; however, because episodes of hypotension/bradycardia and the frequency of interventions were not systematically recorded, the results may reflect the combined impact of anesthetic technique and clinical management rather than anesthesia alone. The use of different induction agents (etomidate versus propofol) also limits the extent to which the observed hemodynamic differences can be attributed solely to the maintenance regimen. The observation of smaller-than-anticipated effect sizes indicates that the study was underpowered to detect differences in overall ischemic burden and biochemical endpoints. In addition, the lack of multivariable analyses prevented clear delineation of the potential confounding effects of variables such as ejection fraction, glycine absorption, and comorbidities. Because the study population consisted predominantly of patients in the low-to-intermediate Goldman risk categories, the findings cannot be generalized to individuals at cardiac risk and should be interpreted as applicable to a specific comorbid patient subgroup.

5. Conclusions

In this study, propofol–remifentanyl-based intravenous anesthesia was associated with a more stable hemodynamic profile than sevoflurane-based balanced anesthesia in ASA II–III patients with cardiovascular comorbidities undergoing monopolar TURP. However, no superiority was demonstrated in terms of overall ST-segment ischemic burden or CK-MB–defined myocardial injury. The lower incidence of ischemia observed at 15 minutes postoperatively should be regarded as a hypothesis-generating finding rather than definitive evidence, given the multiple comparisons and limited sample size.

Although the prospective, randomized design is a strength of the study, the absence of troponin measurements limits the interpretation of the findings within the contemporary MINS framework. Furthermore, an independent association between hemodynamic stability and myocardial injury could not be established because no multivariable adjustment was performed. Accordingly, the findings should be interpreted as exploratory and should not be used to draw a causal conclusion that hemodynamic stability is the primary determinant of myocardial injury or is more important than anesthetic agent selection. The clinical significance of the hemodynamic advantages observed with propofol–remifentanyl-based intravenous anesthesia should be evaluated in larger, multicenter studies using contemporary surgical techniques and incorporating troponin-based MINS endpoints and appropriate multivariable analyses.

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Conflict of Interest

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Data Availability

The datasets generated and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

AI Assistance

No AI-based tools were used in the preparation of this manuscript.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of Ankara Numune Education and Research Hospital (Approval Number & Date: 2001-06-04). Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form. All procedures were conducted in accordance with the Declaration of Helsinki.

Author Contributions

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