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Process optimisation: spinal versus general anaesthesia for endourological surgery. A randomised, controlled trial and machine-learning approach

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Abstract

Background: Data concerning anaesthesia for endourology are rare, and options for it are numerous. Thus, identifying the optimal anaesthesia regimen remains challenging. With this study we aimed to provide the means for selecting optimal anaesthesia for endourology procedures.

Methods: This was a randomised, open-label, controlled study conducted in a single tertiary hospital. Inclusion criteria: American Society of Anesthesiologists (ASA) physical status/risk category I–III, and scheduled surgery time < 60 minutes. Exclusion criteria: contraindications or lack of consent for one of the anaesthesia types, intellectual disabilities, pregnancy, breastfeeding, and refusal to participate. The participants were divided into 3 groups: G1, spinal anaesthesia (SPA) with bupivacaine; G2, SPA with prilocaine; G3, total intravenous anaesthesia (TIVA) with remifentanil and propofol. The primary outcome measure was time to ambulation, while the secondary outcome measures included perioperative hypotension. The results are presented as mean ± SD or median [IQR].

Results: In total, 117 patients completed the study. The time to ambulation (minutes) was significantly different between all groups: 187.95 ± 49.82, 161.05 ± 46.28, and 129.14 ± 63.75 min, for G1, G2 and G3, respectively. The mean arterial pressure drop from baseline during the procedure was most pronounced in G3 (35% [30–44], $P < 0.001$) and lowest in G2 (18% [12–27], $P < 0.001$ vs. G3, NS vs. bupivacaine). Machine-learning models were trained and demonstrated satisfactory performance in predicting the time spent in recovery.

Conclusions: In the context of endourological surgery, the time required for ambulation was shortest when using TIVA, while SPA with hyperbaric prilocaine provides the closest approximation to optimal anaesthesia.

Key words: spinal anaesthesia, machine learning, cost analysis, endourological surgery, total intravenous anaesthesia.

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Although transurethral endoscopy has been a common surgical technique in urology for years [1], only limited data are available comparing total intravenous anaesthesia (TIVA) and spinal anaesthesia (SPA) in patients undergoing these operative procedures.

As surgical advancements continue, more procedures are performed in an outpatient or fast-track setting, which benefits from short-acting anaesthesia [2]. This is particularly pertinent in endourology, as the procedures tend to be short, and optimal process organisation in the operating theatre is essential to maintain a high level of patient safety [3–5]. Consequently, variables that are critical to the patient, such as adverse events and patient satisfaction, cannot be overlooked when parameters, such as procedure times and cost-effectiveness, are assessed. In this context, the optimal anaesthetic regime question is highly complex. Moreover, these variables depend heavily on local practices and conditions, making generalisation of the study data challenging.

The objective of this study was to facilitate the decision-making process for clinicians between TIVA and SPA with prilocaine or bupivacaine. The primary aim was to compare intravenous general anaesthesia with remifentanil and propofol with SPA with

prilocaine or bupivacaine. We evaluated the impact on procedural outcomes in patients undergoing elective endourological surgery, including potential side effects, patient and surgeon satisfaction, cost analysis and postoperative pain relief.

METHODS

Ethical approval for the study was provided by the Ethics Committee of the Regional Medical Council of Brandenburg (protocol number: S 17 (a)/2013) on 27 August 2013. This trial was registered in the German Clinical Trials Register (DRKS00005172) prior to commencement.

Study design

All patients provided written informed consent. Patients were then randomly assigned according to a computer-generated randomisation table prepared by one of the investigators (KS). Participants were enrolled in the pre-operative clinic. Finally, the anaesthetist on duty in the urology operating room (OR) opened the pre-prepared randomisation envelopes, thus completing the assignment of participants to one of three groups:

Group 1: SPA with bupivacaine. SPA was performed in a sitting position, and the primary puncture site was defined as L3/4. If unsuccessful, the secondary site was left to the anaesthetists' discretion. Finally, hyperbaric bupivacaine 12.5 mg (Carbostesin, AstraZeneca, 5 mg mL^{-1}) was administered with a volume of 2.5 mL (12.5 mg). Anaesthesia spread was then assessed using a pin-prick method with a dulled needle. The procedure was started when at least the Th8 dermatome was anaesthetised.

Group 2: SPA with prilocaine. SPA was performed analogously to the bupivacaine group, but 3 mL (60 mg) of hyperbaric prilocaine (Takipril, Sintectica) was administered after successful spinal puncture instead.

Group 3: TIVA. TIVA was induced with remifentanil 0.5–1.0 μg kg^{-1} min^{-1} and propofol 5 mg kg^{-1} h^{-1} for 3 min, followed by a bolus of 1.5–2.0 mg kg^{-1} propofol. After successfully placing the laryngeal mask, remifentanil and propofol dosages were reduced to 0.1–0.15 μg kg^{-1} min^{-1} and 4–6 mg kg^{-1} h^{-1}, respectively. TIVA was then titrated to maintain a bispectral index (BIS) of 45–55, and the infusion was stopped at the end of the procedure. As soon as the patient was awake, they were extubated and transferred to the recovery room. Postoperative analgesia was administered at the anaesthetist's discretion.

Inclusion/exclusion criteria:

a) ASA I–III;
b) elective endourological surgery;
c) scheduled surgery time < 60 min.

Exclusion criteria were as follows:

a) contraindications for one of the anaesthesia types, such as allergy to any study medication, severe bleeding disorders or severe lung disease;
b) mental retardation;
c) pregnancy and breastfeeding;
d) inability to provide informed consent;
e) no consent for one of the anaesthesia types, SPA or TIVA.

Question 1: How would you rate your overall satisfaction with anaesthesia? *

Question 2: Did you feel safe during the procedure?**

Question 3a: Did you experience any unpleasant moments before the anaesthesia?**

Question 3b: - during the anaesthesia?**

Question 3c: - after the anaesthesia?**

Question 4: Would you be willing to have this kind of anaesthesia again?**

FIGURE 1. Patients' satisfaction questionnaire. Rating scales: *was from 1 (very dissatisfied) to 5 (fully satisfied). **1 (yes) to 5 (no). Questions 2 and 4 were control questions, as the best possible answer was 1 and not 5. Prior to analysis, those answers were converted so they would align with the others

Outcomes

The primary outcome was the time from the start of anaesthesia to achieving ambulation. The start of anaesthesia was defined as the time point when the patient was already in the operating theatre, all monitoring and equipment were on and functioning, and the anaesthesiologist was ready to begin the appropriate procedure. Ambulation was achieved in the recovery room when the patient met the following criteria:

a) Aldrete score [6] > 8;
b) pain on the Visual Analogue Scale (VAS) < 4;
c) signs of postoperative bleeding.

In the SPA groups further criteria were added:

d) Bromage score [7] = 0;
e) sensory blockade < Th12.

It should be noted that the patients were not required to be able to stand up on their own. As urological patients frequently require bladder catheters, miction was not employed as a criterion for ambulation.

Secondary outcomes included:

a) perioperative hypotension was defined as a 20% change from the first blood pressure measurement in the OR (baseline);
b) side effects such as postoperative nausea and vomiting, shivering, vertigo or syncope, pruritus and back pain;
c) pain score on the VAS;
d) patient satisfaction (Figure 1);
e) surgeon's satisfaction rated on a scale from 0 (very dissatisfied) to 4 (fully satisfied);
f) cost analysis, based on our hospital prices.

Statistical analysis

Prior to the study, a power analysis was performed. Based on the previous results [8, 9], we estimated the mean time to ambulation after TIVA at 95 min with an SD of 19 min and after prilocaine at 91 min with an SD of 40 min. We hypothesised a normal distribution and that a difference of 30 min would be of clinical significance. We assumed an α-error of 0.0125 (Bonferroni correction) with a power of 80%. A sample of 38 patients for each group would satisfy these criteria. The analysis was performed using G*Power Version 3.1.5 (Franz Faul, Universität Kiel, Germany).

The analysis was performed using ANOVA with the post-hoc pairwise Student's *t*-test with Holm's *P*-correction, the Kruskal-Wallis test with post-hoc Mann-Whitney *U* test, or the χ^2 test where appropriate. All analyses were performed using RStudio Version 1.0.44 and R Version 3.2.

Finally, two post-hoc analyses were performed. Firstly, the assumption that more analgesics would be required in the first 24 hours postoperatively after TIVA than SPA was explored, as it does not provide long-lasting pain relief. To evaluate this assumption, data about analgesic consumption in the first 24 hours after the operation were retrospectively collected. Secondly, three common machine-learning (ML) algorithms were applied.

Machine learning approach

ML algorithms can be employed to identify solutions that are adjusted to account for local conditions. In essence, ML enables a computer to perform tasks for which it was not explicitly programmed. These tasks can be broadly classified as either classification tasks or numerical predictions. In the former, an algorithm assigns a class to unseen data. To determine the likelihood of postinduction hypotension in a patient, for instance, the algorithm would provide either "hypotension" or "no hypotension." The latter provides a numerical answer, for example, an expected postinduction blood pressure drop of 25%. However, training ML models can be technically challenging for clinicians. Therefore, we created an easy-to-use R package called farseer, which applies our training solution automatically on locally gathered data. It can be done by a simple function call. The source code and R package are publicly available on GitHub (https://github.com/skitek/farseer). They are licensed under the GNU GPL v. 3.0, which permits their use and modification in future research. Once trained, farseer models can be used to simulate the outcome variables, such as costs, process times and changes in mean arterial pressure (MAP).

Data collection

Selection of input variables

We used all the patient characteristic variables collected in the study as input variables. These included age, weight, height, sex, ASA class, type of operation, study group, body mass index (BMI), and planned duration. They were selected because they are readily available for every patient and commonly used in clinical practice when choosing appropriate anaesthesia. We did not perform further variable selection, because we aimed for as automated and simple a process as possible.

Target selection

The following targets were selected: a) the time spent in the recovery room, as a surrogate for the primary outcome; b) hypotension during the procedure, as a surrogate for the patient outcome; c) material and medication costs associated with the procedure. These targets were selected, because of their clinical significance and strong statistical differences found in our study. The aforementioned steps were performed manually. The following process was automated using farseer.

Prior to the implementation of ML, the continuous variables were normalised using minimum–maximum feature scaling. This process involves transforming the values of a variable to a number within the range of 0 to 1. This step is crucial as it eliminates the confounding factor of different unit scales used in different variables.

For the factor variables, an analogous step to normalisation was taken, namely transformation of binary factors. This refers to factors with levels of 1 (yes) or 0 (no). For a factor with n distinct levels, it is done by creating n-1 binary factors. To illustrate, our group variable had three levels initially (bupivacaine, prilocaine, TIVA), and these were changed to binary factors: bupivacaine group and prilocaine group. Bupivacaine and prilocaine groups were then identified by having 1 in a corresponding binary factor, and TIVA by having 0 in both.

Choice of algorithms

We selected multiple regression as a well-established and widely used algorithm in medical research. Partition Tree [10] and artificial neural networks [11, 12] represent the more modern approach to ML. Further details on these algorithms can be found in the Supplementary Material.

Model training

We used supervised learning for both, classification and numerical prediction. A random 75% of the data sample was used as training data, with

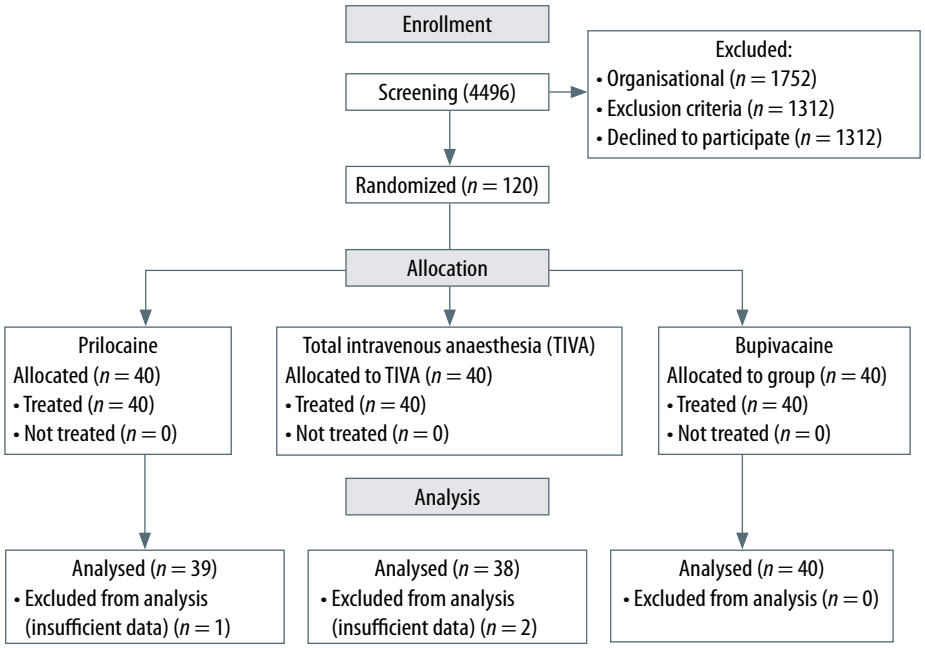


FIGURE 2. CONSORT flowchart

TABLE 1. Summary of patient data

Factor	Bupivacaine $n = 40$	Prilocaine $n = 39$	TIVA $n = 38$
Age (years)	63 ± 11	69 ± 11*	60 ± 10
Male/Female, *n*/*n*	35/5	34/5	30/8
Weight (kg)	83.83 ± 17.47	84.82 ± 14.0	82.89 ± 16.05
Height (cm)	173.68 ± 9.32	174.18 ± 7.8	173.86 ± 10.11
ASA	2 (2–2)	2 (2–2)	2 (2–2)
Scheduled operation time (min)	60 (30–60)	45 (35–60)	45 (32–60)
Procedures			
TUR – Prostate	18	14	9
TUR – Bladder	11	11	13
Ureteroscopy	5	12	10
DJ insertion	3	1	4
Urethrotomy	1	1	0
DJ removal	1	0	0
TUR-P + TUR-B	0	0	1
TUR-B + DJ insertion	1	0	0
Data missing	0	0	1

DJ – double-J catheter, TIVA – total intravenous anaesthesia, TUR – trans-urethral resection
*Statistical significance vs. both other groups, the cut-off for significance was $P = 0.05$ after Holm's correction.

the remaining 25% subsequently employed to assess the models.

Model validation

As our performance measure, we utilised the following: a) correlation between predicted and observed data; b) Bland-Altmann plots for numeric predictions; and c) area under the curve for classification models.

Data prediction

The validated models could now be employed to predict the impact of the selected anaesthesia regimen on the specified output variables.

RESULTS

The data acquisition occurred in a single tertiary hospital (Carl-Thiem Hospital, Cottbus, Germany) from November 2013 to June 2016, and 120 patients were randomised. Three patients were not included in the analysis due to insufficient data – two in the TIVA group and one in the prilocaine group. One patient in the TIVA group accidentally received sevoflurane instead of propofol, but was not excluded from the analysis as per the intention-to-treat principle. The CONSORT flowchart is presented in Figure 2.

Patients' characteristics are presented in Table 1. We unexpectedly detected a statistically significant difference in age between the prilocaine group and the other groups.

Primary outcome

The time to ambulation was shortest in the TIVA group, 32 min and 58 min shorter than in the prilocaine and bupivacaine groups, respectively (Table 2).

Secondary outcomes

In our secondary analysis to further explore this difference, we found that TIVA took more time

TABLE 2. Process times

	Bupivacaine	Prilocaine	TIVA
Time to ambulation [min]	188 ± 50*	161 ± 46*	129 ± 64*
Total time in OR[1] [min]	56.0 [39.0–71.0]	50.0 [45.5–65.0]	58.5 [40.0–77.2]
Non-surgical time in OR[2] [min]	20.5 [18.0–26.0] **	23.0 [20.0–30.0]**	28.0 [25.0–33.2]*
Induction [min]	15.0 [12.0–19.2]	17.0 [15.0–20.0]	15.0 [12.0–19.0]
Reversal [min]	5.0 [4.0–10.0]**	5.0 [4.0–10.0]**	12.0 [10.0–15.0]*
Recovery room [min]	118.0 [85.0–142.5]*	97.0 [70.0–128.5]*	47.0 [17.0–77.0]*

[1]Sum of induction, procedure and reversal times. [2]Sum of induction and reversal times. Statistical significance vs. *both other groups, **TIVA, ***prilocaine, ****bupivacaine. The tests were either pairwise t-test (primary outcome) or pairwise Mann-Whitney *U* test. The cut-off for significance was $P = 0.05$ after Holm's correction

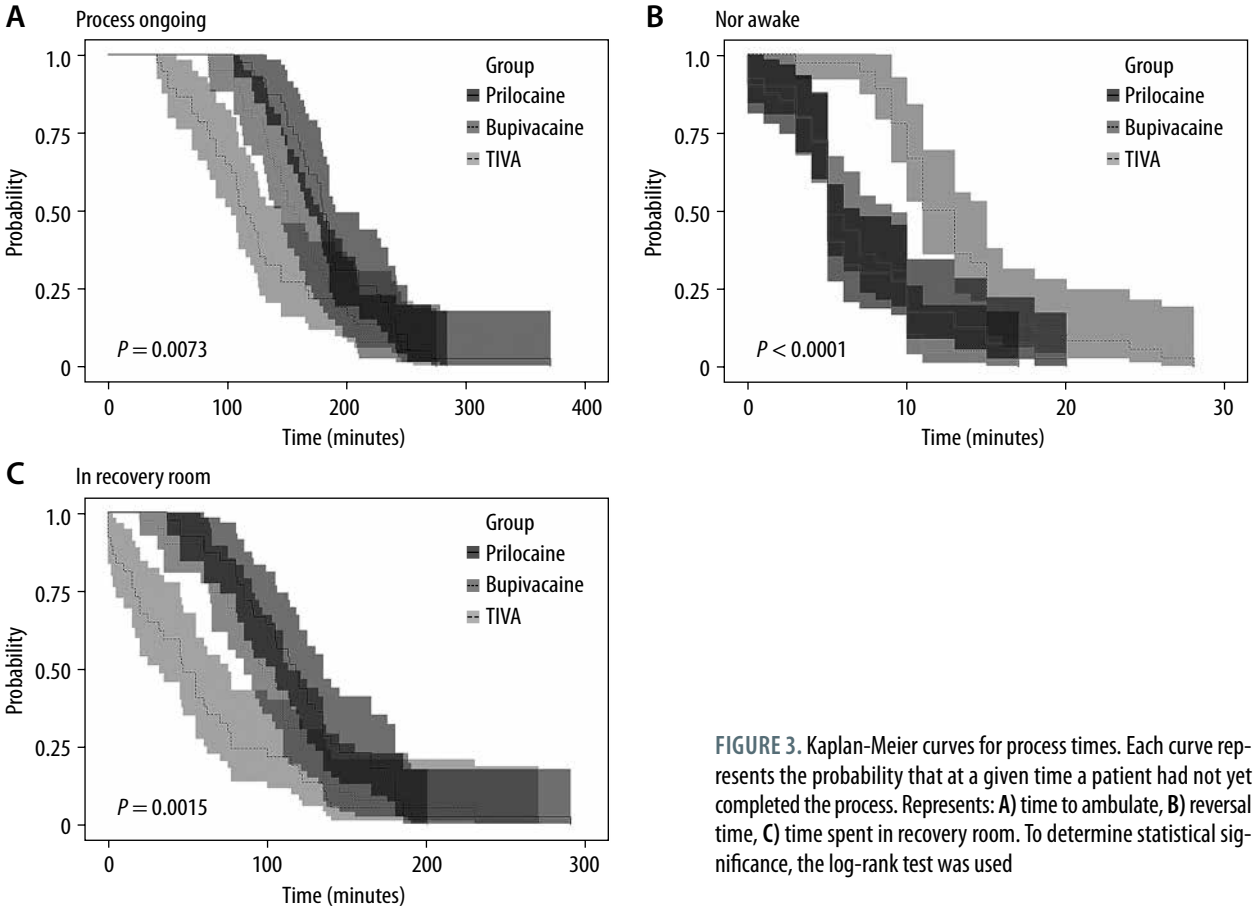


FIGURE 3. Kaplan-Meier curves for process times. Each curve represents the probability that at a given time a patient had not yet completed the process. Represents: **A)** time to ambulate, **B)** reversal time, **C)** time spent in recovery room. To determine statistical significance, the log-rank test was used

to perform in the OR than both SPA groups. Most of the difference could be attributed to prolonged anaesthesia reversal, with no difference in anaesthesia induction time. However, time spent in the recovery room was significantly shorter after general anaesthesia (Table 2, Figure 3).

There was no difference in baseline MAP between the groups. After induction, MAP during the procedure followed two distinct courses. In TIVA, there was a steep fall that was maintained throughout the procedure but disappeared during emergence from anaesthesia. In both SPA groups, the initial fall was far less present but detectable in the recovery room. MAP returned to normal in all groups prior to ambulation, but was significantly lower than baseline. Presenting this phenomenon as relative figures, the median blood pressure drop during the procedure was 23% (12–27) in bupivacaine, 18% (12–27) in prilocaine vs. 35% (30–44) in TIVA. In the recovery room, hypotension was common in both SPA groups (30/38 in bupivacaine, $P < 0.005$ vs. TIVA; not significant (NS) vs. prilocaine, 21/36 in prilocaine, $P = 0.02$ vs. TIVA and 9/35 in TIVA). However, analysing the blood pressure from baseline to the median value in the recovery room, the difference was less pronounced and not clinically significant (Table 3). Analysed as a contingency table, in the bupivacaine group, there were 11/38 cases with hypotension in the recovery room, $P = 0.005$ vs. TIVA, NS vs. prilocaine, 8/36 in prilocaine, $P = 0.02$ vs. TIVA and 0/35 in TIVA. No difference was detected in other vital parameters.

TABLE 3. Mean arterial blood pressure during the perioperative period

	Bupivacaine	Prilocaine	TIVA
Induction			
Maximum	90.97 ± 11.29	91.85 ± 10.39	89.32 ± 11.85
(min)			
Minimum	80 (73–87)**	84 (78–88)**	63 (55–71)*
Median	84.91 ± 10.81**	85.94 ± 9.72**	77.19 ± 12.68*
Procedure			
Maximum	79.83 ± 11.11**	83.74 ± 9.6**	68.43 ± 10.44*
(min)			
Minimum	69.5 ± 10.26**	73.56 ± 10.51**	55.65 ± 8.47*
Median	73.94 ± 10.06*	78.73 ± 9.81*	61.68 ± 7.91*
Emergence			
Maximum	75.95 ± 10.55	79.37 ± 9.93	77.09 ± 13.56
(min)			
Minimum	72 (67–78)**	76 (71–82)**	62.5 (56–68)*
Median	75 (67–78)**	78 (72–82)**	66 (62–73)*
Recovery			
Maximum	80 (74–85)	83 (76–88)	85 (81–89)****
[min]			
Minimum	64 ± 8.25*	69 ± 8.23*	76.2 ± 11.63*
Median	72.63 ± 8.31	76.94 ± 7.88	81.19 ± 9.43****

Statistical significance vs. *both other groups, **TIVA, ***prilocaine, ****bupivacaine. Values are presented as mean ± SD or median (IQR) as appropriate. Tests were either pairwise *t*-tests or the pairwise Mann-Whitney *U* test as appropriate. The cut-off for significance was $P = 0.05$ after Holm's correction.

There was no difference in patient and surgeon satisfaction scores or side effects. Two patients in our study suffered severe adverse effects, one being urethra rupture and the other postoperative sepsis of unknown origin. Although the latter patient unfortunately died, anaesthesia could not have caused or influenced this outcome.

Regarding cost analysis, TIVA is the least cost-efficient, costing €36 (58%) more than any of the alternatives (Table 4).

Maximum VAS in the recovery room was higher in TIVA (2.5 [1–5] vs. 1[1–1] in both SPA groups, $P < 0.001$) and remained higher throughout the recovery room stay.

Post-hoc analysis

There was no difference in overall analgesic consumption. As the medications administered were varied and consumption low, we collapsed the data into a binary medication given/no medication. Corresponding to our findings about VAS, medication was more commonly administered to TIVA patients in the recovery room. This difference disappeared, however, once the patient was transferred to the ward (Table 5).

Machine learning approach

Concerning our ML approach, the measures for time in recovery are presented in Figures 4 and 5. Both figures were produced by farseer. The ANN and linear regression models demonstrated satisfactory performance in numerical prediction, whereas the partition tree model failed to provide useful information. In the classification task, where models were tasked with predicting whether the patient's stay in the recovery room would exceed the average length of stay, all models performed similarly. The partition tree model exhibited superior performance in numerical prediction of costs and hypotension. Further details regarding the costs and hypotension can be found in the supplementary material. Predictions for a random patient from the validation dataset are presented in Table 6.

DISCUSSION

TIVA provided the shortest time to ambulation but was associated with more intraoperative hypotension and higher costs. Both SPA methods are cost-effective, but hypotension may occur in the recovery room. However, this is less common when prilocaine is used. Under clinical conditions, this drug allows for a similar ambulation time as TIVA. Therefore, we recommend using SPA with prilocaine in this setting, followed by TIVA and bupivacaine.

Previously, Flaishon *et al*. [13] conducted a study involving patients with prostate cancer undergoing brachytherapy. Their findings indicated that TIVA with propofol and fentanyl as a bolus allows

TABLE 4. Estimated costs

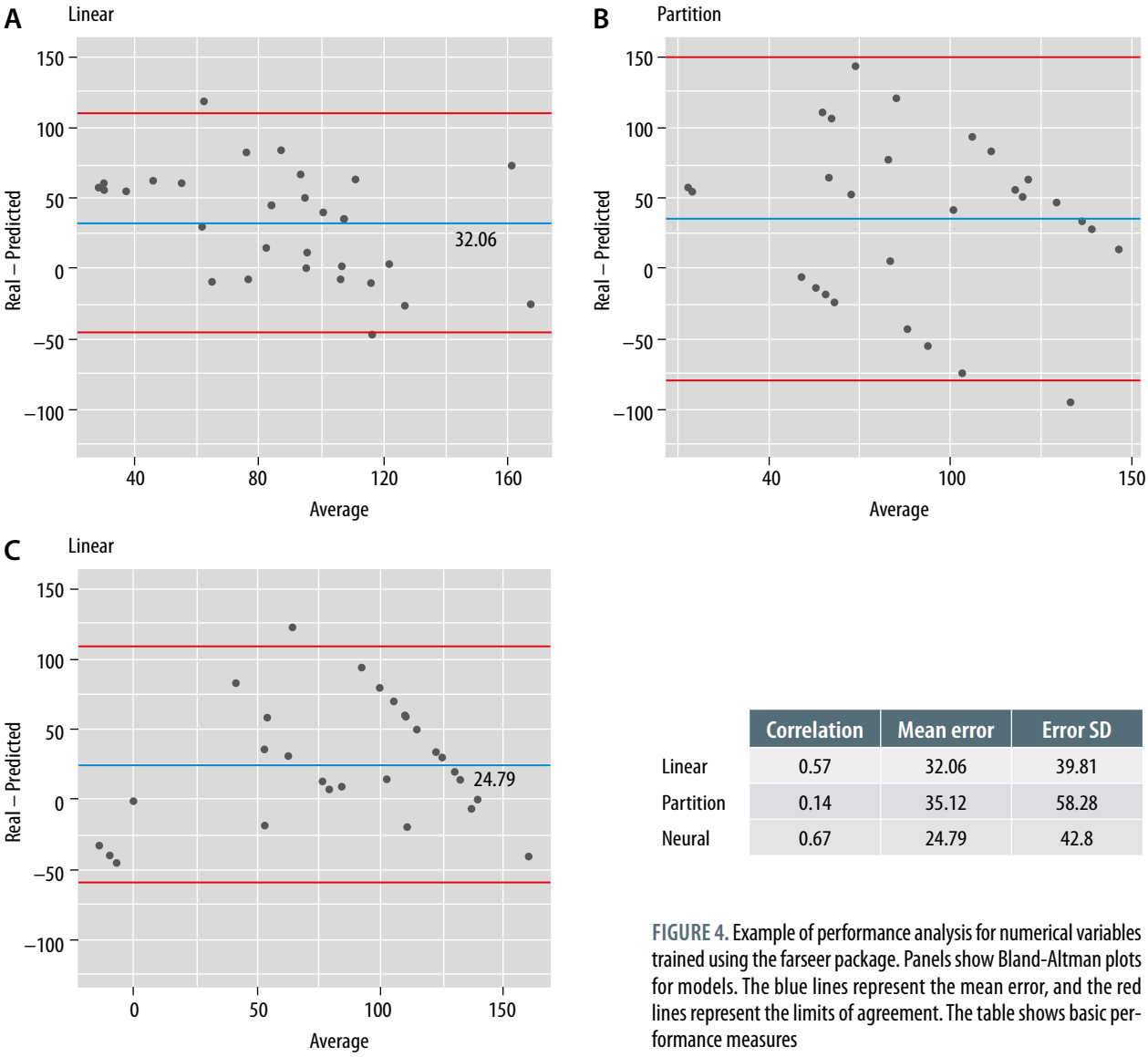
Costs (€)	TIVA	Bupivacaine	P (vs. TIVA)	Difference (€)	Prilocaine	P (vs. TIVA)	Difference (€)	P (Prilocaine vs. Bupivacaine)	Difference (€)
General	97.80 (75–116)	61.96 (51–75)	< 0.001	35.84	62.69 (55–78)	< 0.001	35.11	0.825	0.73
Without personnel	65.70 (58–73)	30.01 (25–36)	< 0.001	35.69	32.61 (27–32)	< 0.001	33.09	0.544	2.60
Without BIS	79.20 (57–97)	61.96 (51–75)	0.097	17.24	62.69 (55–78)	0.097	16.51	–	–
Without BIS and personnel	47.10 (39–55)	30.01 (25–36)	< 0.001	17.09	32.61 (27–32)	< 0.001	14.49	–	–

Values are presented as median (IQR). For statistical evaluation, the Mann-Whitney *U* test with Holm's correction was used.
BIS – bispectral index, TIVA – total intravenous anaesthesia

TABLE 5. Analgesic usage after the procedure

	Bupivacaine	Prilocaine	TIVA	Prilocaine vs. Bupivacaine	Bupivacaine vs. TIVA	Prilocaine vs. TIVA
Recovery						
No medication*	28	29	14	NS	0.023	0.018
Medication**	11	10	21			
Ward						
No medication	33	25	26	NS	NS	NS
Medication	6	14	9			
Overall						
No medication	23	19	14	NS	NS	NS
Medication	16	20	23			

*Number of patients who did not receive pain medication. **Number of patients requiring pain medication. χ^2 test with P cut-off of 0.05.



	Correlation	Mean error	Error SD
Linear	0.57	32.06	39.81
Partition	0.14	35.12	58.28
Neural	0.67	24.79	42.8

FIGURE 4. Example of performance analysis for numerical variables trained using the farseer package. Panels show Bland-Altman plots for models. The blue lines represent the mean error, and the red lines represent the limits of agreement. The table shows basic performance measures

patients to ambulate earlier than SPA with either 2.5 mg or 5 mg of bupivacaine. Erhan *et al*. [8] obtained comparable outcomes in patients undergoing varicocele repair; they compared TIVA with remifentanil and propofol with SPA with the addition of low-dose bupivacaine and fentanyl. Danielli *et al*. [14] also found TIVA to be superior in outpatient gynaecological patients. Tyritzis *et al*. [15] examined postoperative pain after transurethral resection of the prostate (TUR-P) or bladder (TUR-B).

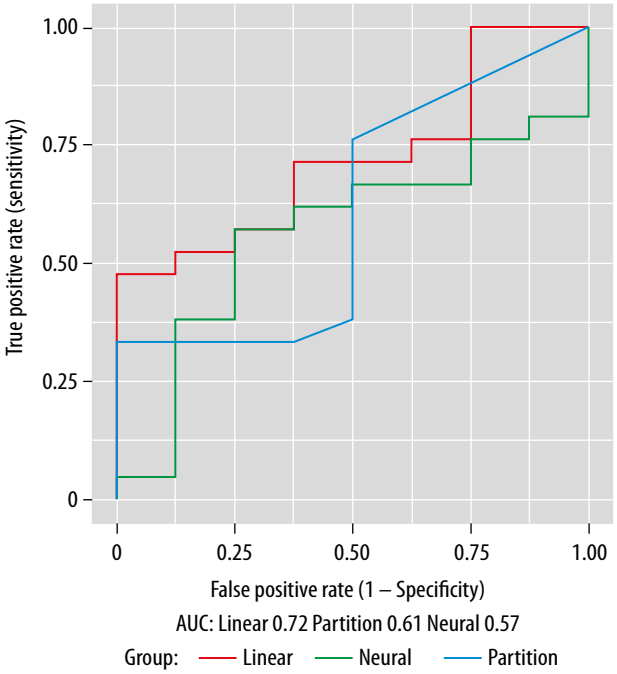


FIGURE 5. Example of performance analysis for a categorical variable (time in recovery factor) produced with the farseer package. Prior to analysis a new variable, called Time_in_Recovery_Factor, was created for each patient. Firstly, the mean time spent in recovery across all groups was calculated. Then, if actual time spent for a given patient was longer, Time_in_Recovery_Factor was set to "high" for this case and "low" otherwise. AUC – area under the curve

However, none of these studies compared the short-acting prilocaine and TIVA.

Regarding our primary objective, TIVA provided the shortest time to ambulation, while SPA was associated with prolonged ambulation time. However, the clinical meaning of this finding is not clear. It is surprising that, despite the high number of non-cardiac surgical procedures performed annually worldwide, there is a paucity of studies on the time spent in the recovery room or other organisational or structural analyses after non-cardiac surgery. In the host institution of this study (Carl-Thiem-Klinikum Cottbus), a patient typically spends at least one hour, with a maximum of approximately two hours. It can be argued that prilocaine allows for virtually identical time to ambulation as TIVA. Conversely, bupivacaine seems to prolong the time to ambulation. Our cost analysis concurs with similar studies performed in different surgical settings [16, 17].

Our secondary analysis revealed other clinically relevant findings. Hypotension events in the recovery room are more common in the case of SPA and most common with bupivacaine. It may be of relevance in patients at high risk, as stabilising such patients may prove challenging. Conversely, TIVA appears to cause more profound hypotension by induction. It is also important to note that blood pressure remained within the clinically acceptable range for the majority of patients across all groups. With regard to other adverse events, there was little to no difference between the groups. This is not unexpected, given that severe complications in endourology are rare [18] and are not typically attributable to anaesthesia.

The results demonstrated that high levels of patient and surgeon satisfaction were achieved in all groups. This outcome was contrary to expectations in the TIVA group, given the assumption that patients would be more dissatisfied due to the increased incidence of postoperative pain. This finding is consistent with the study by Tyritzis *et al*. [15], but contradicts studies in other surgical fields [19, 20]. However, even if the VAS scores were higher, they were still very low, which would explain this phenomenon. Although our evaluation of surgeon satisfaction was simple, lack of differences between groups suggests similar viability. A similar approach was recently successfully applied by Shetabi *et al*. [21] to detect differences between sedation methods by double-J removal.

TIVA is associated with higher costs. However, if we deduct the cost of BIS monitoring, which is still under discussion to avoid awareness or delirium [22, 23] and not standard in all hospitals, only a non-statistically significant difference can be seen, and the difference drops to 28% (€18). Nevertheless, without neuromonitoring, side effects such as awareness or hypotension tend to be more common [22]. Furthermore, an additional analysis was conducted without including personal costs, which did not alter the overall results (Table 4). Both SPA groups exhibited comparable cost-effectiveness. In a recent study of patients undergoing lumbar spine surgery, the ob-

TABLE 6. Predictions for a random patient not used for training models

Simulated group	Costs (€)			Time in recovery (min)			Change of MAP (%)		
	Linear	Partition	Neural	Linear	Partition	Neural	Linear	Partition	Neural
Bupivacaine	28.89	33.68	43.46	149.7	121.29	139.27	–19	–17	20
Prilocaine	26.91	33.6	43.46	126	66.57	111.02	–14	–23	-20
TIVA	63.53	63.77	43.46	98.39	66.57	100	–35	–34	-23

Each row contains predicted values under the assumption that this patient would have been in a specified row name. Predictions are given according to linear regression, partition tree and artificial neural networks. For full information according to training and simulation, please refer to Supplementary Material. Change of MAP represents the predicted change from baseline MAP to median MAP during the procedure. MAP – mean arterial pressure, TIVA – total intravenous anaesthesia

served difference in the operating room was 19% and 10% overall [24]. However, it is important to note that Morris *et al*. [24] compared overall costs and not just anaesthesia-related costs, as was done in this study. The authors posit that if both anaesthesia techniques perform similarly, the question of costs becomes clinically important to the patient.

The pain relief provided by SPA seems advantageous, as both VAS scores in the recovery room and pain medication consumption are lower than in TIVA (Table 5). This effect concurs with studies in other clinical settings, such as obstetrics and orthopaedics [19, 25]. However, it should be noted that we did not routinely provide pain relief on emergence from anaesthesia, as this was not a common practice in the host institution.

The two SPA groups differed regarding injected volumes, with the bupivacaine group having a lower volume. Lower SPA volume is associated with lower block spread and shorter block time [26, 27]. This once more demonstrates the superiority of prilocaine over bupivacaine, as it allows for a higher block without prolonging ambulation.

However, it is possible that more than one answer to our question may be deemed correct, as none of the three tested solutions met all the predefined criteria.

The problem of choosing an anaesthetic form is complex and cannot be solved with a single study or even a full battery of such experiments, as it will not address all the local problems. The organisation of anaesthesia can vary widely between hospitals. It is paramount, for example, if a hospital uses induction rooms. In such a case, the next patient receives anaesthesia concurrently with the emergence of the patient treated before them. Consequently, the advantage of using short-acting drugs is reinforced, and the time from induction to the end of the surgery tends to be shorter [28]. Conversely, the use of more cost-effective, longer-acting drugs or types of anaesthesia, such as SPA with bupivacaine, may be advantageous in hospitals without them. By facilitating rapid recovery, TIVA appears to be an optimal choice for urgent procedures in institutions lacking 24-hour recovery rooms. An exhaustive list of potential discrepancies is unfeasible to produce if we attempt to address these issues globally, and studies addressing them are regrettably scarce.

We addressed this problem by creating models using common ML algorithms. Similar models have been recently constructed for intraoperative hypotension by Kendale *et al*. using retrospective data. ML has been demonstrated to be beneficial for both pre-anaesthesia evaluation and intraoperative hypoxaemia [29-31]. ML has also been employed in critical care research, with encouraging outcomes that have surpassed every existing clinical tool [32, 33]. Nevertheless, even the most effective models reflect only data used to train them, limiting their widespread applicability. Consequently, we propose an alternative, innovative approach. Rather than focusing on identifying a single optimal model, future studies should aim to provide guidance on the optimal methodology for local model training. Local training offers several advantages, including the ability to avoid the sharing of sensitive patient data over the Internet. Ideally, it would provide clinicians with an accessible tool for the automated training of models. Should the effectiveness of farseer be demonstrated in this context, it will have significant clinical applications, as it will permit the selection of anaesthesia that is tailored to the specific needs of individual patients. To the best of our knowledge, no such tool has previously been designed for use in our field.

LIMITATIONS

It must be acknowledged that the present study is subject to several limitations. It was not possible to blind the study between SPA and TIVA, due to the inherent differences in the injection volumes administered in the SPA groups. This reflects clinical practice at the host institution, which the study was bound to closely follow. Secondly, it should be noted that the procedure times and costs presented here are specific to the host institution and therefore not generally applicable. In particular, cost analysis is highly susceptible to local conditions. This is because personnel, drug and equipment costs are subject to significant fluctuations and tend to evolve over time.

Thirdly, the patients in our cohort were healthier than the average endourology patients at the host hospital, which undoubtedly influenced the frequency of adverse events, such as hypotension. Furthermore, our study lacked sufficient statistical power to fully assess patient safety.

Fourthly, our study might have lacked sufficient power to assess all of the secondary outcomes. In particular, the measurement of surgeons' satisfaction was based on one question only. Further studies on assessing it are needed.

Fifthly, the open-label design introduces bias, affecting the objectivity of outcome assessments. Participants and investigators know the treatment being administered, which can influence subjective outcomes such as patient and surgeon satisfaction scores.

Finally, with regard to ML models, our study lacks sufficient statistical power to enable the construction of accurate models, rendering them unsuitable for clinical decision-making.

CONCLUSIONS

In the context of endourological surgery with a planned duration of less than 60 minutes, it can

be concluded that the shortest time to ambulation is achieved with TIVA. At the same time, SPA with hyperbaric prilocaine (60 mg) provides the closest approximation to optimal anaesthesia, but hyperbaric bupivacaine provides little benefit. However, the ML models developed in this study are not yet sufficiently accurate for clinical use. Consequently, we have developed a user-friendly R package to facilitate further improvements.

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REFERENCES

1. Brannen GE. Endourology in perspective. Urology 1986; 28: 161-172. DOI: 10.1016/0090-4295(86)90035-x.
2. Borendal Wodlin N, Nilsson L, Carlsson P, Kjølhede P. Cost-effectiveness of general anesthesia vs spinal anesthesia in fast-track abdominal benign hysterectomy. Am J Obstet Gynecol 2011; 205: 326.e1-7. DOI: 10.1016/j.ajog.2011.05.043.
3. Abdelwahab O, Habous M, Aziz M, Sultan M, Farag M, Santucci R, et al. Bipolar vaporization of the prostate may cause higher complication rates compared to bipolar loop resection: a randomized prospective trial. Int Urol Nephrol 2019; 51: 2143-2148. DOI: 10.1007/s11255-019-02280-5.
4. Hayashida Y, Miyata Y, Matsuo T, Ohba K, Sakai H, Taba M, et al. A pilot study to assess the safety and usefulness of combined transurethral endoscopic mucosal resection and en-bloc resection for non-muscle invasive bladder cancer. BMC Urol 2019; 19: 56. DOI: 10.1186/s12894-019-0486-0.
5. Pietropaolo A, Bres-Niewada E, Skolarikos A, Liatsikos E, Kallidonis P, Aboumarzouk O, et al. Worldwide survey of flexible ureteroscopy practice: a survey from European Association of Urology sections of young academic urologists and uro-technology groups. Centr Eur J Urol 2019; 72: 393-397. DOI: 10.5173/ceju.2019.0041.
6. Ding D, Ishag S. Aldrete Scoring System. StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024.
7. Craig D, Carli F. Bromage motor blockade score – a score that has lasted more than a lifetime. Can J Anaesth 2018; 65: 837-838. DOI: 10.1007/s12630-018-1101-7.
8. Erhan E, Ugur G, Anadolu O, Saklayan M, Ozyar B. General anaesthesia or spinal anaesthesia for outpatient urological surgery. Eur J Anaesthesiol 2003; 20: 647-652. DOI: 10.1017/s0265021503001042.
9. Rätsch G, Niebergall H, Hauenstein L, Reber A. Spinal anaesthesia in day-case surgery. Optimisation of procedures. Der Anaesthesist 2007; 56: 322-327 [Article in German]. DOI: 10.1007/s00101-007-1141-9.
10. Podgorelec V, Kokol P, Stiglic B, Rozman I. Decision trees: an overview and their use in medicine. J Med Syst 2002; 26: 445-463. DOI: 10.1023/a:1016409317640.
11. Fasel B. An introduction to bio-inspired artificial neural network architectures. Acta Neurol Belg 2003; 103: 6-12.
12. Hashimoto DA, Witkowski E, Gao L, Meireles O, Rosman G. Artificial intelligence in anesthesiology: current techniques, clinical applications, and limitations. Anesthesiology 2020; 132: 379-394. DOI: 10.1097/ALN.0000000000002960.
13. Flaishon R, Ekstein P, Matzkin H, Weinbroum AA. An evaluation of general and spinal anesthesia techniques for prostate brachytherapy in a day surgery setting. Anesth Analg 2005; 101: 1656-1658. DOI: 10.1213/01.ANE.0000184205.43759.55.
14. Danelli G, Berti M, Casati A, Albertin A, Deni F, Nobili F, et al. Spinal block or total intravenous anaesthesia with propofol and remifentanil for gynaecological outpatient procedures. Eur J Anaesthesiol 2002; 19: 594-599. DOI: 10.1017/s0265021502000960.
15. Tyritzis SI, Stravodimos KG, Vasileiou I, Fotopoulou G, Koritsiadis G, Migdalis V, et al. Spinal versus general anaesthesia in postoperative pain management during transurethral procedures. ISRN Urol 2011; 2011: 895874. DOI: 10.5402/2011/895874.
16. Chakladar A, White SM. Cost estimates of spinal versus general anaesthesia for fractured neck of femur surgery. Anaesthesia 2010; 65: 810-814. DOI: 10.1111/j.1365-2044.2010.06382.x.
17. Finsterwald M, Muster M, Farshad M, Saporito A, Brada M, Aguirre JA. Spinal versus general anesthesia for lumbar spine surgery in high risk patients: perioperative hemodynamic stability, complications and costs. J Clin Anesth 2018; 46: 3-7. DOI: 10.1016/j.jclinane.2018.01.004.
18. Cornu JN, Herrmann T, Traxer O, Matlaga B. Prevention and management following complications from endourology procedures. Eur Urol Focus 2016; 2: 49-59. DOI: 10.1016/j.euf.2016.03.014.
19. Ghaffari S, Dehghanpisheh L, Tavakkoli F, Mahmoudi H. The effect of spinal versus general anesthesia on quality of life in women undergoing cesarean delivery on maternal request. Cureus 2018; 10: e3715. DOI: 10.7759/cureus.3715.
20. Wilson JM, Farley KX, Erens GA, Guild GN. General vs spinal anesthesia for revision total knee arthroplasty: do complication rates differ? J Arthroplasty 2019; 34: 1417-1422. DOI: 10.1016/j.arth.2019.03.048.
21. Shetabi H, Akrami Moghaddam F, Kazemi R. Comparison of intravenous sedation with propofol, dexmedetomidine and midazolam in double-J ureteral stent removal. Am J Clin Exp Urol 2023; 11: 160-167.
22. Lewis SR, Pritchard MW, Fawcett LJ, Punjasawadwong Y. Bispectral index for improving intraoperative awareness and early postoperative recovery in adults. Cochrane Database Syst Rev 2019; 9: CD003843. DOI: 10.1002/14651858.CD003843.pub4.
23. Gao WW, He YH, Liu L, Yuan Q, Wang YF, Zhao B. BIS monitoring on intraoperative awareness: a meta-analysis. Curr Med Sci 2018; 38: 349-353. DOI: 10.1007/s11596-018-1886-1.
24. Morris MT, Morris J, Wallace C, Cho W, Sharan A, Abouelrigal M, et al. An analysis of the cost-effectiveness of spinal versus general anesthesia for lumbar spine surgery in various hospital settings. Global Spine J 2019; 9: 368-374. DOI: 10.1177/2192568218795867.
25. Hu S, Zhang ZY, Hua YQ, Li J, Cai ZD. A comparison of regional and general anaesthesia for total replacement of the hip or knee: a meta-analysis. J Bone Joint Surg Br 2009; 91: 935-942. DOI: 10.1302/0301-620X.91B7.21538.
26. Axelsson KH, Edstrom HH, Sundberg AE, Widman GB. Spinal anaesthesia with hyperbaric 0.5% bupivacaine: effects of volume. Acta Anaesthesiologica Scandinavica 1982; 26: 439-445. DOI: 10.1111/j.1399-6576.1982.tb01796.x.
27. Chambers WA, Littlewood DG, Edstrom HH, Scott DB. Spinal anaesthesia with hyperbaric bupivacaine: effects of concentration and volume administered. Br J Anaesth 1982; 54: 75-80. DOI: 10.1093/bja/54.1.75.
28. Hanss R, Buttgereit B, Tonner PH, Bein B, Schleppers A, Steinfath M, et al. Overlapping induction of anesthesia: an analysis of benefits and costs. Anesthesiology 2005; 103: 391-400. DOI: 10.1097/00000542-200508000-00023.
29. Kendale S, Kulkarni P, Rosenberg AD, Wang J. Supervised machine-learning predictive analytics for prediction of postinduction hypotension. Anesthesiology 2018; 129: 675-688. DOI: 10.1097/ALN.0000000000002374.
30. Lundberg SM, Nair B, Vavilala MS, Horibe M, Eisses MJ, Adams T, et al. Explainable machine-learning predictions for the prevention of hypoxaemia during surgery. Nat Biomed Eng 2018; 2: 749-760. DOI: 10.1038/s41551-018-0304-0.
31. Sobrie O, Lazouni MEA, Mahmoudi S, Mousseau V, Pirlot M. A new decision support model for preanesthetic evaluation. Comput Methods Programs Biomed 2016; 133: 183-193. DOI: 10.1016/j.cmpb.2016.05.021.
32. Meyer A, Zverinski D, Pfahringer B, Kempfert J, Kuehne T, Sundermann SH, et al. Machine learning for real-time prediction of complications in critical care: a retrospective study. Lancet Respir Med 2018; 6: 905-914. DOI: 10.1016/S2213-2600(18)30300-X.
33. Awaysheh A, Wilcke J, Elvinger F, Rees L, Fan W, Zimmerman KL. Review of medical decision support and machine-learning methods. Vet Pathol 2019; 56: 512-525. DOI: 10.1177/0300985819829524.