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The Novice Overshoot: A Bispectral Index-Based Analysis of the Anesthesiology Resident Learning Curve for Anesthetic Depth Control in Supervised Practice

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ABSTRACT

Introduction: The skillful management of anesthetic depth is a cornerstone of anesthesiology, yet the objective characterization of the resident learning curve remains underexplored. This study aimed to quantitatively map the developmental trajectory of anesthetic depth control among anesthesiology residents in a supervised clinical environment. **Methods:** We conducted a prospective, cross-sectional, observational study involving 21 anesthesiology residents (from seven sequential semesters of training) and 105 ASA I-II adult patients at a tertiary academic hospital. Under standardized supervision, residents induced general anesthesia. The primary outcome was the Bispectral Index (BIS) value and its categorical distribution (Deep: <40, General: 40-60, Sedation: >60) at 2 minutes post-intubation. Secondary outcomes included propofol induction dose and hemodynamic responses. Data were analyzed using ANOVA, Kruskal-Wallis, and Chi-square tests. **Results:** Post-intubation mean BIS values showed a non-significant trend towards being lower in junior residents compared to seniors ($p=0.088$). However, the categorical distribution of BIS values differed significantly across training levels ($p=0.015$). Junior residents (Semesters I-II) induced a state of deep anesthesia (BIS < 40) in 46.7% of their patients, compared to only 11.1% for senior residents (Semesters V-VII) ($p<0.001$). This correlated with junior residents using significantly higher weight-adjusted propofol doses (2.4 ± 0.3 mg/kg vs. 1.9 ± 0.2 mg/kg; $p<0.001$). **Conclusion:** The anesthesiology resident learning curve is characterized by a distinct pattern of initial over-titration, or a "novice overshoot," leading to a higher incidence of unnecessarily deep anesthesia. While mean BIS values did not differ significantly, the distribution of hypnotic states reveals a critical educational target. BIS monitoring serves as a valuable objective tool for tracking the performance of the resident-supervisor dyad, offering data-driven insights for enhancing competency-based training and patient safety.

1. Introduction

General anesthesia represents one of modern medicine's most profound interventions, creating a controlled, reversible state of unconsciousness that enables complex surgical procedures.[1] The practice of anesthesiology is defined by the safe and effective delivery of this state, which encompasses amnesia, analgesia, akinesia, and autonomic stability. Central to this practice is the precise titration and management of anesthetic depth, a dynamic and delicate balance between preventing the psychological trauma of intraoperative awareness and avoiding the physiological trespass of excessive sedation.[2] Inadequate depth risks the catastrophic experience of awareness with recall, an event that can inflict severe and lasting post-traumatic stress disorder.[3] Conversely, an excessively deep anesthetic state—a far more common occurrence—is not a benign condition. It is independently associated with a cascade of adverse outcomes, including dose-dependent hemodynamic instability, prolonged emergence from anesthesia, and an increased incidence of postoperative nausea and vomiting (PONV). More insidiously, a growing body of evidence suggests a strong association between deep anesthesia, particularly in vulnerable populations, and long-term neurocognitive sequelae, including postoperative delirium (POD) and postoperative cognitive dysfunction (POCD).[4]

For generations, the art of gauging anesthetic depth relied on a clinical gestalt synthesized from indirect signs: autonomic responses such as tachycardia and hypertension, somatic responses like patient movement, and changes in respiratory patterns. The advent and routine use of neuromuscular blocking agents (NMBAs), however, rendered the most reliable sign of light anesthesia—patient movement—obsolete, compelling a reliance on less specific autonomic markers that can be confounded by surgical stimulation, hypovolemia, or patient comorbidities.[5] This clinical challenge precipitated the development of technologies aimed at directly assessing the hypnotic component of the anesthetic state by processing the brain's electrical activity.

The processed electroencephalogram (EEG) has emerged as the standard of care for this purpose, and among available devices, the bispectral index (BIS) monitor is the most extensively validated and widely adopted in clinical practice. BIS technology employs a proprietary algorithm to analyze complex frontal EEG waveforms, converting them into a single, dimensionless number from 100 (fully awake) to 0 (isoelectric silence).[6] A BIS value between 40 and 60 is universally recommended as the target range for adequate surgical anesthesia, a therapeutic window demonstrated to minimize the risk of awareness while mitigating the dangers of excessive central nervous system suppression.

The journey from a newly minted medical graduate to a proficient, independent anesthesiologist is governed by the structured crucible of residency training. Modern medical education has pivoted from a time-based model to a framework of competency-based milestones and entrustable professional activities (EPAs).[7] The ability to skillfully and safely induce and maintain an appropriate depth of anesthesia is arguably one of the most fundamental of these EPAs. This complex skill requires the seamless integration of pharmacological knowledge, procedural dexterity, vigilant monitoring, and adaptive intelligence to respond to individual patient physiology.[8] Historically, the assessment of this competency has been largely subjective, relying on the direct observation and qualitative feedback of supervising faculty. While indispensable, this method is susceptible to inter-rater variability and lacks the granular, objective data needed to precisely track progress and identify specific areas for improvement.

Despite the ubiquitous presence of BIS monitors in modern operating rooms, their potential as an objective tool for delineating the resident learning curve has been surprisingly underexplored in the literature.[9] There is a scarcity of quantitative research that maps the evolution of a resident's ability to control the hypnotic state from their first tentative inductions as a novice to their near-independent practice in the final years of training. Characterizing this trajectory is not merely an academic exercise; it is fundamental to advancing patient safety and educational science. A detailed understanding of the learning curve allows for the development of targeted educational interventions, the early identification of residents who may benefit from additional support, and the validation of competency-based progression metrics.[10]

Therefore, the primary aim of this study was to objectively map the learning curve of anesthesiology residents in managing anesthetic depth during the critical phase of induction, using BIS as the primary quantitative metric. We hypothesized that a distinct and measurable learning curve would be evident, characterized by specific, predictable patterns of anesthetic depth control that differ between junior and senior residents. The novelty of this research lies in its rigorous, quantitative approach to characterizing the development of a core clinical skill within the complex, real-world context of supervised practice. By analyzing the performance of the resident-supervisor dyad, this study provides crucial, data-driven insights for optimizing competency-based medical education, enhancing formative feedback mechanisms, and ultimately reinforcing patient safety protocols within teaching institutions.

2. Methods

This prospective, cross-sectional, observational study was conducted in the Department of Anesthesiology and Intensive Therapy at Dr. Saiful Anwar Regional General Hospital in Malang, Indonesia. This facility serves as a provincial tertiary care center and the primary teaching hospital for the Faculty of Medicine, Universitas Brawijaya. The study protocol was designed and executed in strict accordance with the principles outlined in the Declaration of Helsinki and received full approval from the Institutional Research Ethics Committee of Universitas Brawijaya. The study was conducted between April 2024 and December 2024. Written informed consent, detailing the study's observational nature, monitoring procedures, data confidentiality, and the right to withdraw at any time, was obtained from all participating residents and patients prior to any study-related activities.

A consecutive sampling strategy was employed for patient enrollment to minimize selection bias. The resident and patient cohorts were defined by the following criteria: Resident Cohort: Inclusion Criteria: All anesthesiology residents (Program Pendidikan Dokter Spesialis - PPDS) currently in semesters 1 through 7 were eligible for participation. All participants had successfully completed their foundational training and passed their institutional Direct Observation of Procedural Skills (DOPS) assessment for standard endotracheal intubation. To ensure a representative sample from each training level, the first three unique residents from each semester to have an eligible patient case during the study period were included, for a total of 21 residents. Exclusion Criteria: Residents who had not completed the mandatory institutional induction protocol training were excluded. Patient Cohort: Inclusion Criteria: Patients aged 18 to 65 years with an American Society of Anesthesiologists (ASA) physical status of I or II, scheduled for elective surgical procedures requiring general anesthesia with endotracheal intubation, were eligible. Exclusion Criteria: Patients were excluded for factors that could confound BIS interpretation or increase anesthetic risk beyond the scope of the study. These included: known or suspected central nervous system pathology (epilepsy, stroke, dementia); current use of psychoactive medications; a pre-operative Glasgow Coma Scale (GCS) score below 15; known allergies to any study medications (propofol, fentanyl, midazolam, atracurium, sevoflurane); or contraindications to frontal BIS sensor placement (facial trauma, skin infection). Patients with severe or unstable hemodynamic status were also excluded.

A total of 21 unique residents were enrolled. Each resident managed 5 unique patients, resulting in a total of 105 patient datasets, with 15 patient data points for each of the seven semester groups. To isolate the variable of resident skill level, all monitoring and anesthetic procedures were rigorously standardized. Upon arrival in the operating room, patients were connected to standard non-invasive monitors, including 5-lead electrocardiography (ECG), non-invasive blood pressure (NIBP) set to cycle every 3 minutes, pulse oximetry (SpO_2), and end-tidal capnography ($EtCO_2$) following intubation. A BIS™ Quatro four-electrode sensor was applied to the patient's forehead after meticulous skin preparation with an isopropyl alcohol swab to ensure skin impedance was below 5 kΩ. The sensor was connected to a standalone Covidien BIS™ monitor, and data was allowed to stabilize for at least 3 minutes to establish a reliable baseline BIS value before induction. BIS monitoring is a standard of care for a wide range of procedures at the study institution, ensuring that all residents and supervisors were familiar with its use, thereby minimizing any potential Hawthorne effect.

To avoid confounding sedative effects, no routine sedative pre-medication was administered. The induction of anesthesia was performed by the participating resident. The standardized sequence involved the intravenous administration of Fentanyl 2 μg/kg, followed by Midazolam 0.03 mg/kg. One minute after the administration of opioids and benzodiazepines, the resident began the titration of Propofol to achieve loss of consciousness. Loss of consciousness was defined clinically by the loss of the eyelash reflex. The total dose of propofol required to meet this endpoint was recorded. Immediately following loss of consciousness, Atracurium 0.5 mg/kg was administered to facilitate orotracheal intubation. Following confirmation of successful intubation via bilateral auscultation and sustained $EtCO_2$, anesthesia was maintained with Sevoflurane in a 50% oxygen/air mixture. The resident was responsible for adjusting the end-tidal sevoflurane concentration to maintain hemodynamic stability and a target BIS value between 40 and 60.

All anesthetics were conducted under the direct, in-room supervision of an attending anesthesiologist, reflecting the standard practice in a teaching hospital. The pool of supervisors consisted of 10 board-certified anesthesiologists with a mean of 12.5 years of post-specialization experience. To mitigate bias, supervisors were not assigned based on resident seniority. Instead, the on-call attending for that specific operating room served as the supervisor. All supervisors were briefed on the study protocol and were explicitly instructed to act purely as observers and not to interfere with the resident's management—verbally or physically—unless they judged that a patient safety threshold was about to be breached. A breach was prospectively defined as: sustained (> 1 min) severe hypotension (MAP < 55 mmHg) or hypertension (MAP > 120 mmHg), severe bradycardia (HR < 40 bpm) or tachycardia (HR > 120 bpm), or oxygen desaturation (SpO_2 < 90%).

All data were prospectively recorded by a dedicated, independent research assistant who was not part of the clinical care team. The following outcomes were measured: Primary Outcomes: Mean BIS Value: The stable BIS value was recorded at three discrete time points: T1 (Baseline) just prior to induction; T2 (Post-Intubation) at exactly 2 minutes after successful endotracheal intubation; and T3 (Post-Incision) at exactly 5 minutes after the initial surgical incision; Categorical BIS Distribution: The primary analytical focus was on the BIS value at T2, which was categorized into three clinically relevant groups: Deep Anesthesia (BIS < 40), General Anesthesia (BIS 40–60), and Sedation/Light Anesthesia (BIS > 60); Secondary Outcomes: Propofol Induction Dose: The total propofol dose (mg) was normalized for patient body weight (mg/kg); Induction Variables: The time from the start of propofol injection to loss of consciousness (seconds) was recorded; Hemodynamic Response: Mean Arterial Pressure (MAP) and Heart Rate (HR) were recorded at T1, T2, and T3. The percentage change from baseline was calculated; Incidence of Deep Anesthesia: The proportion of patients in each group with a BIS value < 40 at the T2 time point; Incidence of Hypotension: The proportion of patients who experienced a drop in MAP of more than 20% from baseline at any point within the first 10 minutes following induction.

Data were analyzed using IBM SPSS Statistics for Windows, Version 26.0 (Armonk, NY). Statistical significance was set a priori at a two-tailed p-value of < 0.05. The Shapiro-Wilk test was used to assess the normality of continuous data distribution. Normally distributed data were summarized as means and standard deviations (SD), while non-normally distributed data were presented as medians and interquartile ranges (IQR). Categorical data were summarized as frequencies and percentages. To compare outcomes across the seven semester groups, a one-way analysis of variance (ANOVA) was used for normally distributed continuous variables, with Welch's ANOVA applied if the assumption of homogeneity of variances (assessed by Levene's test) was violated. The Kruskal-Wallis H test was used for non-normally distributed continuous data. The Chi-square test or Fisher's exact test was used for categorical data as appropriate.

For outcomes showing a significant overall difference, post-hoc pairwise comparisons were performed to identify which specific groups differed. For ANOVA with unequal variances, Tamhane's T2 test was used; for the Kruskal-Wallis test, the Dunn-Bonferroni test was used to adjust for multiple comparisons. Spearman's rank correlation coefficient (ρ) was used to assess the relationship between the resident's training semester (as a continuous variable from 1 to 7) and key outcomes like propofol dose and post-induction BIS value. For a more focused analysis of the effect of experience, residents were categorized into two groups: Junior (Semesters I-II, n=30) and Senior (Semesters V-VII, n=45). This grouping was justified based on the institutional curriculum, where semesters I-II represent the foundational phase and semesters V-VII represent the advanced/pre-attending phase. Outcomes between these two groups were compared using Student's t-test or the Mann-Whitney U test for continuous variables and the Chi-square test for categorical variables.

3. Results

The study successfully enrolled 21 residents and 105 patients, with data from all participants included in the final analysis. The demographic and clinical characteristics of both the resident and patient cohorts were exceptionally well-matched across the seven semester groups, with no statistically significant differences observed in age, gender, BMI, or ASA physical status (all p > 0.05). This homogeneity ensures that any observed differences in anesthetic outcomes are more likely attributable to the resident's training level rather than baseline patient variability. A detailed summary is provided in Table 1.

Table 1. Demographic and clinical characteristics.

A comparative analysis of baseline characteristics for resident and patient cohorts across seven training semesters.

CHARACTERISTIC	SEMESTER I (N=15)	SEMESTER II (N=15)	SEMESTER III (N=15)	SEMESTER IV (N=15)	SEMESTER V (N=15)	SEMESTER VI (N=15)	SEMESTER VII (N=15)	P-VALUE
Resident Data								
Age (years), mean ± SD	31.7 ± 2.9	29.0 ± 0.0	31.3 ± 2.1	31.0 ± 4.4	32.0 ± 3.5	31.3 ± 1.2	33.0 ± 3.6	0.350
Gender, n (%) Male	100%	100%	66.7%	66.7%	66.7%	100%	33.3%	0.390
Patient Data								
Age (years), mean ± SD	42.1 ± 11.2	43.5 ± 10.8	41.9 ± 12.1	44.0 ± 11.5	42.8 ± 10.9	43.2 ± 11.7	42.5 ± 12.3	0.981
Gender, n (%) Male	7 (46.7%)	8 (53.3%)	7 (46.7%)	9 (60.0%)	8 (53.3%)	6 (40.0%)	8 (53.3%)	0.895
BMI (kg/m²), mean ± SD	24.1 ± 3.1	23.8 ± 2.9	24.5 ± 3.3	23.9 ± 3.0	24.2 ± 3.2	24.0 ± 2.8	23.7 ± 3.1	0.992
ASA Status, I / II n	10 / 5	9 / 6	11 / 4	10 / 5	9 / 6	10 / 5	11 / 4	0.976

Note: Data are presented as mean ± SD for continuous variables or n (%) for categorical variables. The p-value indicates no statistically significant differences in baseline characteristics across the semester groups (p > 0.05 for all). Statistical tests used were ANOVA for continuous data and Chi-square test for categorical data.

The mean BIS values at baseline (T1) and 5 minutes post-incision (T3) showed no significant differences across the seven semester groups (p=0.240 and p=0.997, respectively), indicating consistent pre-induction states and effective maintenance of anesthesia once the initial phase was complete.

At the primary time point of interest, T2 (2 minutes post-intubation), analysis revealed a distinct trend: mean BIS values were progressively higher with increasing resident seniority. The lowest mean BIS was observed in Semester I (39.7 ± 8.5), while the highest was in Semester V (49.7 ± 7.5). However, when compared across all seven groups, this trend did not reach the threshold for statistical significance in the overall ANOVA test (p=0.088). This suggests that while a relationship exists, it is either not strong enough to be detected as a difference in means with the current sample size, or the true difference lies in the distribution of values rather than the central tendency. The detailed means are presented in Table 2.

The box and whisker plot in Figure 1 visually confirms this finding. It demonstrates that the median BIS values for junior residents (Semesters I-II) are visibly lower than those for senior residents (Semesters V-VII). Furthermore, the interquartile ranges (IQRs) are noticeably wider for the junior groups, illustrating greater variability and less precise control over the anesthetic depth. The most striking finding of this study emerged from the analysis of the categorical distribution of BIS values at T2. The Chi-square test revealed a highly significant difference in how residents at different training levels distributed their patients across the three hypnotic states (Deep Anesthesia: <40, General Anesthesia: 40-60, Sedation: >60) (p=0.015).

Table 2. Mean BIS values at key time points.

Analysis of anesthetic depth, measured by Bispectral Index, at critical procedural moments across all resident training semesters.

BIS VALUE (TIME POINT)	SEM I	SEM II	SEM III	SEM IV	SEM V	SEM VI	SEM VII	P-VALUE
T1: Baseline mean ± SD	89.0 ± 9.2	93.0 ± 6.2	96.3 ± 2.9	85.7 ± 4.9	86.0 ± 3.5	94.3 ± 6.0	92.7 ± 4.7	0.240
T2: Post-Intubation mean ± SD	39.7 ± 8.5	41.3 ± 9.9	43.3 ± 10.2	46.0 ± 8.7	49.7 ± 7.5	48.3 ± 8.0	46.0 ± 7.3	**0.088***
T3: Post-Incision mean ± SD	50.7 ± 13.2	57.0 ± 12.0	54.0 ± 9.3	52.0 ± 9.8	50.3 ± 8.5	50.3 ± 8.5	56.7 ± 7.1	0.997

Note: Data are presented as mean ± SD. Statistical test used was one-way ANOVA.
*The p-value of 0.088 for the T2 time point indicates a strong trend that did not meet the conventional threshold for statistical significance ($p < 0.05$), but prompted the more revealing categorical analysis.

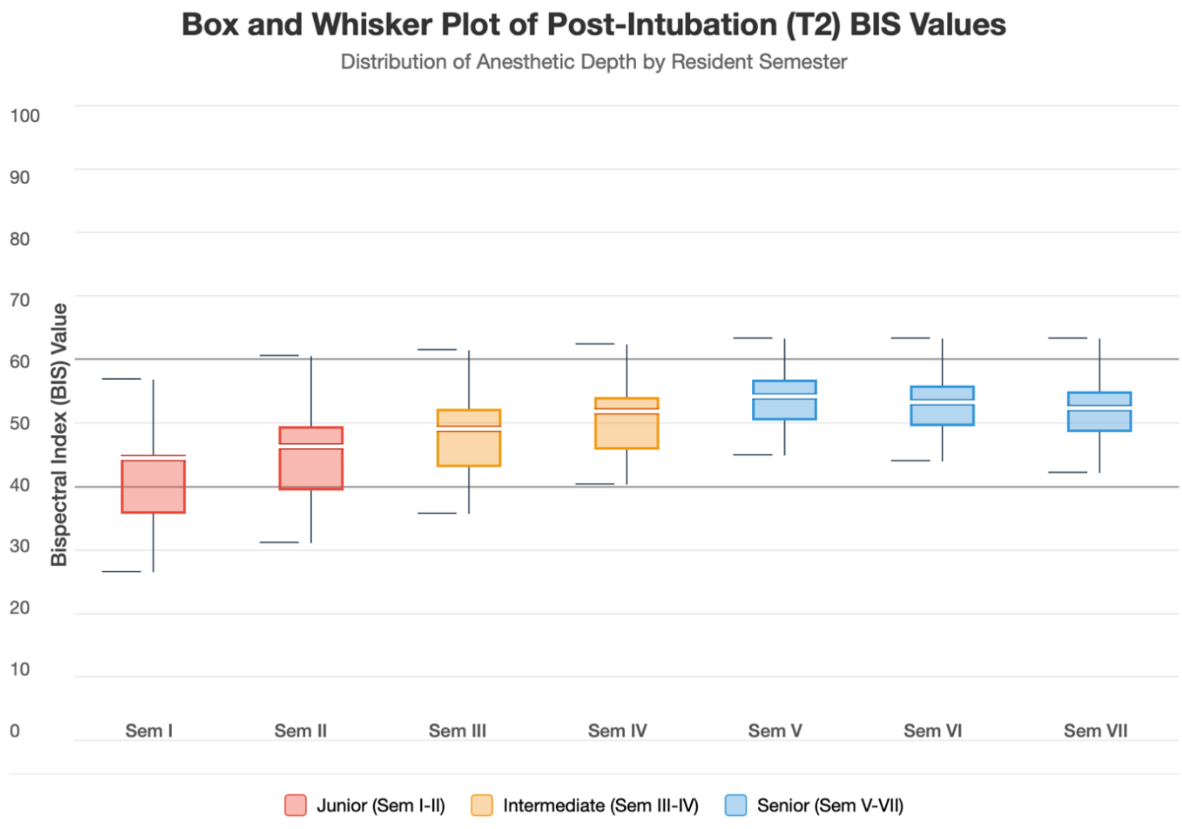

Figure 1. Box and whisker plot of post-intubation (T2) BIS values.

As illustrated in the stacked bar chart in Figure 2, a clear pattern emerges. The proportion of patients induced into a state of 'Deep Anesthesia' (BIS < 40) was highest among the most junior residents and systematically decreased with experience. Specifically, residents in Semesters I and II caused a deep anesthetic state in 46.7% of their patients. This proportion fell to approximately 25% for residents in the intermediate semesters (III-IV) and further to just over 10% for senior residents (Semesters V-VII). Conversely, the proportion of patients maintained within the optimal 'General Anesthesia' range (BIS 40-60) was lowest in the junior cohort and highest in the senior group.

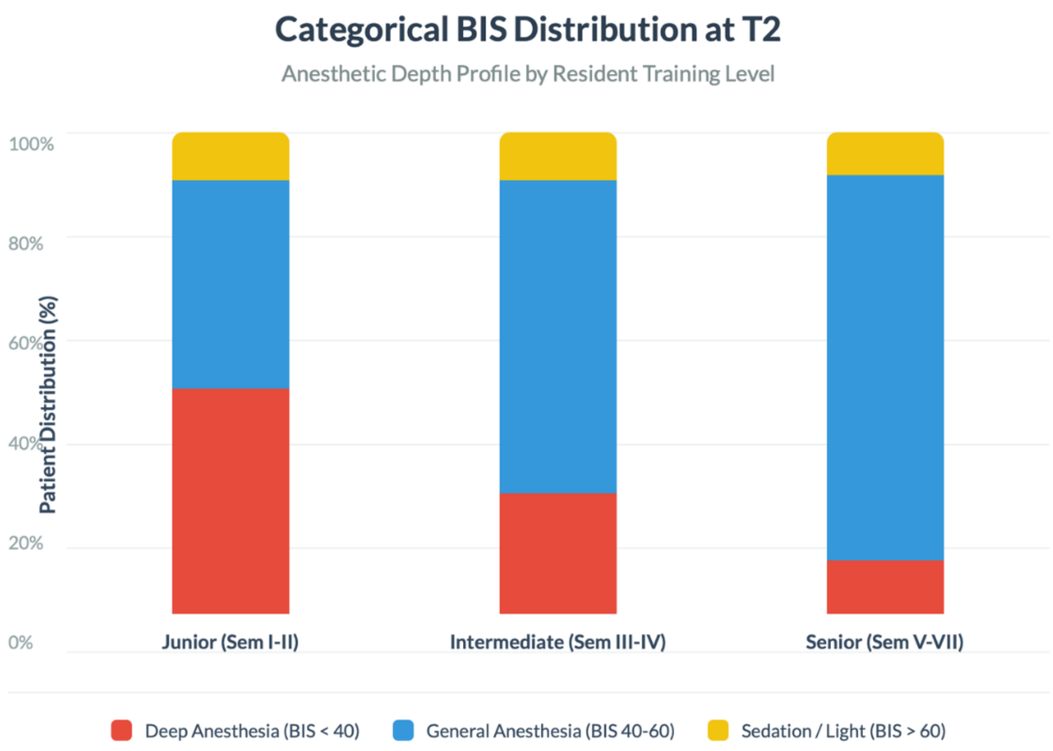

Figure 2. Categorical BIS distribution at T2.

Post-hoc pairwise comparisons confirmed that the anesthetic depth profiles of residents in Semesters I and II were significantly different from those in Semesters V, VI, and VII ($p<0.05$ for all comparisons), establishing a clear statistical distinction between novice and experienced trainees. Key comparisons are detailed in Table 3.

Table 3. Selected pairwise comparisons.

Post-Intubation BIS Category Distribution (Dunn-Bonferroni Post-Hoc Test)

COMPARISON	ADJUSTED P-VALUE	SIGNIFICANCE
Semester I vs. Semester V	0.021	✔ Significant
Semester I vs. Semester VI	0.021	✔ Significant
Semester I vs. Semester VII	0.021	✔ Significant
Semester II vs. Semester V	0.021	✔ Significant
Semester II vs. Semester VI	0.021	✔ Significant
Semester II vs. Semester VII	0.021	✔ Significant
Semester III vs. Semester V	0.817	✘ Not Significant

Analysis of the secondary outcomes provided strong corroborating evidence for the primary findings, as summarized in Table 4. Junior residents (Sem I-II) used a significantly higher weight-adjusted dose of propofol for induction than senior residents (Sem V-VII) (2.4 ± 0.3 mg/kg vs. 1.9 ± 0.2 mg/kg, respectively; $p<0.001$). Consistent with the categorical analysis, the incidence of inducing a BIS < 40 was more than four times higher in the junior group compared to the senior group (46.7% vs. 11.1%; $p<0.001$). While the junior group had a higher incidence of post-induction hypotension (MAP drop > 20%) compared to the senior group (30.0% vs. 17.8%), this difference did not reach statistical significance in our cohort ($p=0.110$). Spearman's correlation revealed a strong, significant negative relationship between a resident's training semester and the propofol dose used ($\rho = -0.58$, $p<0.001$). Conversely, there was a significant positive correlation between training semester and the post-intubation BIS value ($\rho = 0.42$, $p=0.005$), confirming that more senior residents achieve a higher (less deep) BIS level after induction.

Table 4. Secondary outcome.

Comparison Between Junior and Senior Resident Training Levels

OUTCOME	JUNIOR (SEM I-II)	SENIOR (SEM V-VII)	P-VALUE
Propofol Dose mg/kg, mean ± SD	2.4 ± 0.3	1.9 ± 0.2	<0.001
Induction Time seconds, mean ± SD	75 ± 15	82 ± 12	0.062
Incidence of Hypotension n (%)	9 (30.0%)	8 (17.8%)	0.110
Incidence of Deep Anesthesia BIS < 40, n (%)	14 (46.7%)	5 (11.1%)	<0.001

4. Discussion

This study provides a high-resolution, objective map of the anesthesiology resident learning curve for one of the specialty's most fundamental skills: the management of anesthetic depth.[11] The data reveal a clear and compelling narrative of skill acquisition. Our principal finding is not the trivial observation that residents improve with time, but a nuanced characterization of how this improvement manifests. The early phase of anesthesiology training is defined by a significant and quantifiable tendency to "overshoot" the target hypnotic state, resulting in a higher incidence of deep anesthesia (BIS < 40). This "novice overshoot," identified robustly in the categorical distribution of BIS values despite a non-significant difference in the means, offers a profound insight into the maturation of clinical proficiency and carries critical implications for both medical education and patient safety.[12]

The core finding—that junior residents induce a BIS < 40 in nearly half of their patients—can be understood through a combined pharmacological and neurophysiological lens (Figure 3). The primary induction agent, propofol, produces its hypnotic effect via potentiation of the inhibitory neurotransmitter γ-aminobutyric acid (GABA) at the GABA-A receptor. This enhances chloride ion conductance, hyperpolarizing neurons and inhibiting synaptic transmission throughout the central nervous system. The EEG signature of this effect is a shift from low-amplitude, high-frequency beta waves (awake state) to high-amplitude, low-frequency delta and alpha waves (anesthetized state).[13] The BIS algorithm interprets this shift as a decrease in the numerical value.

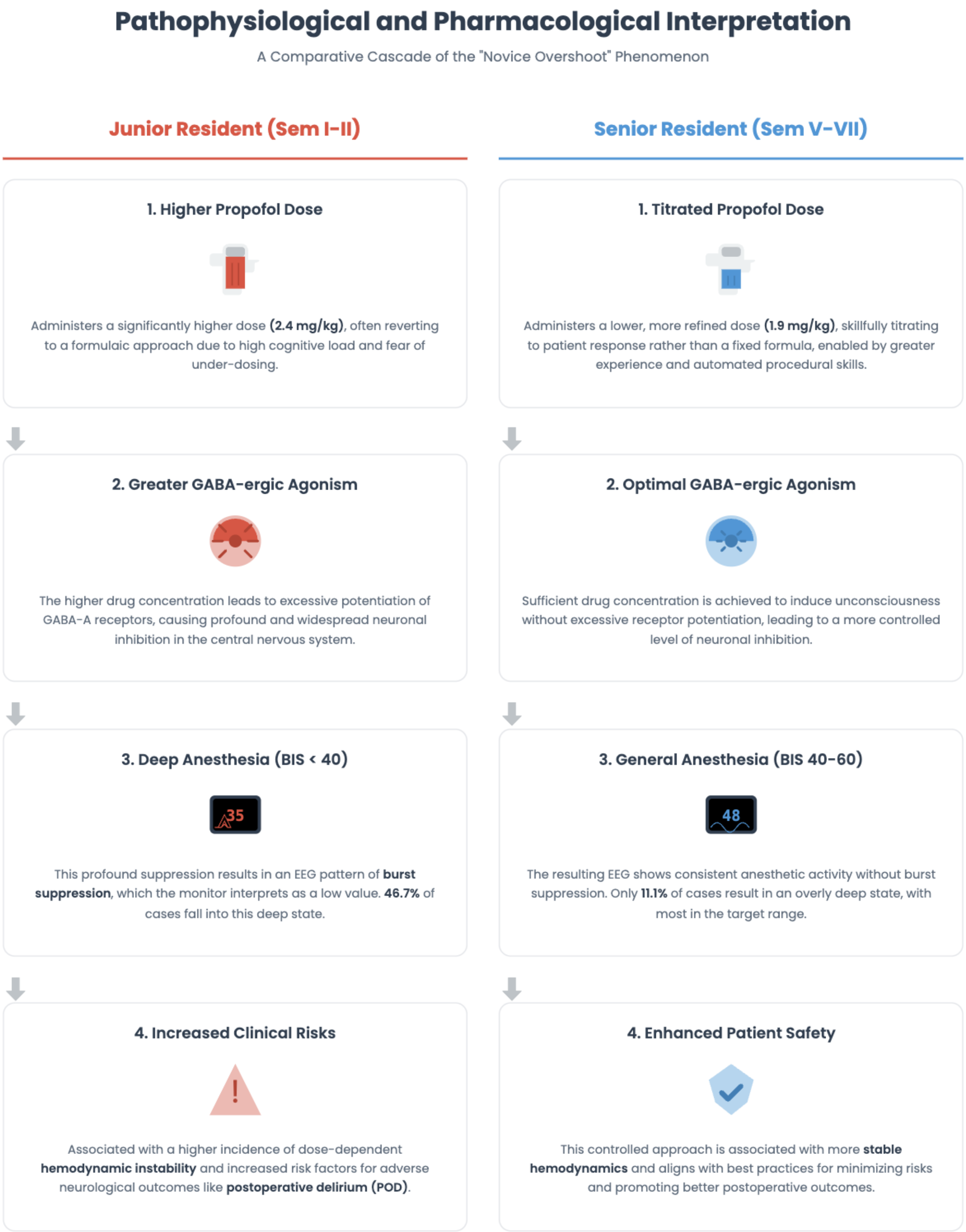

Figure 3. Pathophysiological and pharmacological interpretation.

The significantly higher propofol doses administered by junior residents (2.4 mg/kg) compared to their senior counterparts (1.9 mg/kg) provide a direct pharmacological explanation for the deeper hypnotic states observed. Propofol's effects are steeply dose-dependent. The higher doses used by novices would logically produce higher peak plasma and effect-site concentrations, leading to greater GABA-ergic agonism, more profound cortical suppression, and consequently, a lower BIS nadir.[14] The finding that nearly half of the patients managed by junior residents entered a state of deep anesthesia is pathophysiologically significant. A BIS value below 40 often correlates with the EEG pattern of burst suppression, a state of profound cortical inactivity where periods of isoelectric silence are interspersed with "bursts" of electrical activity. This state is metabolically equivalent to profound cerebral hypometabolism and is generally considered unnecessary for routine surgery.[15] While our study did not measure long-term outcomes, existing literature has linked prolonged intraoperative burst suppression and deep anesthesia to an increased risk of adverse postoperative outcomes, most notably POD. Our findings, therefore, highlight a specific, modifiable practice pattern early in residency that is associated with a known risk factor for adverse neurological outcomes. Furthermore, the trend towards a higher incidence of hypotension in this group, while not statistically significant ($p=0.110$), aligns with the known dose-dependent cardiodepressant effects of propofol and further emphasizes the clinical relevance of over-titration.[16]

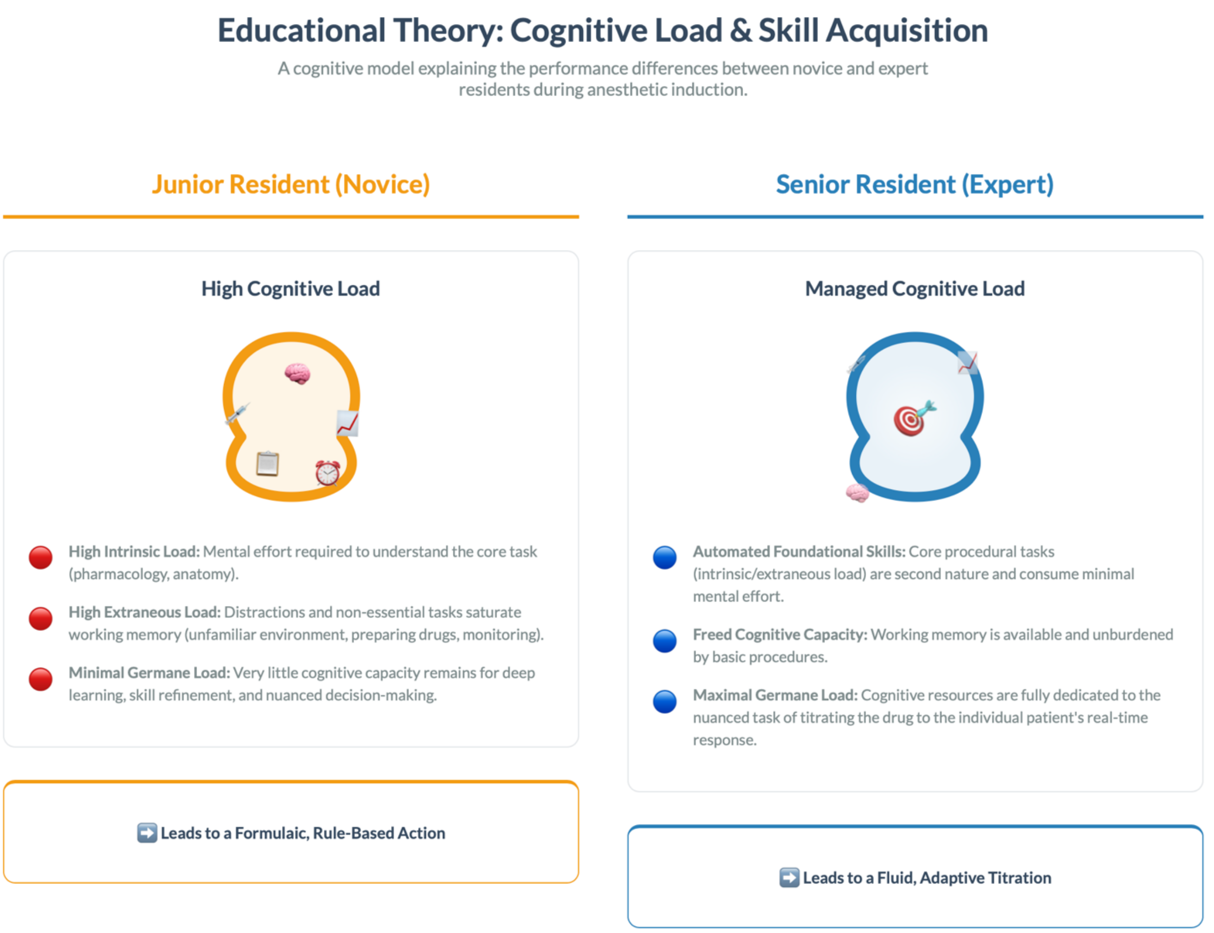

Figure 4. Educational theory: cognitive load and skill acquisition.

The observed "novice overshoot" is elegantly explained by established models of cognitive load and skill acquisition. A junior resident performing an induction is operating under an immense cognitive load. Their working memory is saturated with the intrinsic load of the procedure itself (pharmacology, airway anatomy) and a high degree of extraneous load from the unfamiliar and high-stakes environment.[17] They are simultaneously focused on multiple, non-automated tasks: drawing up and labeling drugs, securing IV access, performing a mask ventilation assessment, and preparing for laryngoscopy. This task saturation leaves minimal cognitive resources for the germane load—the deep processing required for the nuanced, real-time titration of a potent drug based on subtle patient feedback.

Consequently, novices often revert to a more formulaic, rule-based approach: administering a calculated dose (2.5 mg/kg) or pushing the drug until the eyelash reflex is definitively absent. The endpoint itself, "loss of eyelash reflex," is subjective. An inexperienced provider, fearing the catastrophic error of administering a paralytic to an awake patient, is more likely to err on the side of caution, pushing "a little extra" propofol to be absolutely certain. This behavior directly leads to the higher doses and lower BIS values we observed.[18]

In contrast, a senior resident operates according to the Dreyfus model of skill acquisition, progressing from novice to expert. For them, the procedural aspects of induction are largely automated, freeing up significant cognitive capacity to focus on the dynamic patient response and titrating drugs more gracefully to the desired endpoint. The significant negative correlation between training semester and propofol dose ($\rho = -0.58$) and the positive correlation with post-induction BIS ($\rho = 0.42$) are the statistical fingerprints of this journey from novice rigidity to expert fluidity.

A critical and nuanced interpretation of our findings requires acknowledging that we did not measure resident performance in a vacuum. Every anesthetic was administered under the direct supervision of an attending anesthesiologist. Therefore, the outcome measured is the performance of the resident-supervisor dyad. The differential supervision based on resident seniority is an inherent and unavoidable feature of academic medicine. A supervisor provides a much tighter leash for a first-semester resident, offering more frequent verbal cues and being poised to intervene more readily.[19] Conversely, a seventh-semester resident is granted significant autonomy, with the supervisor acting more as a consultant. The "novice overshoot" occurs within this supervised system. It suggests that the institutional or individual supervisor's threshold for intervention is typically not crossed by a BIS of 35 or even 30, as long as hemodynamics remain stable.[19] The learning curve we observed is thus a reflection of the entire educational system's accepted latitude for performance variability. The improvement over time reflects not only the resident's growing skill but also the supervisor's growing trust, which allows the resident to practice with increasing independence.

Our findings have powerful implications for anesthesiology education. BIS monitoring can be a transformative tool for data-driven feedback. Instead of subjective comments like "you gave too much propofol," a supervisor can use the BIS trend to provide concrete, objective feedback in real-time. For example: "See that number? It's 45. The patient is unconscious. You can stop your infusion now, and we can avoid the dip to 35 that we saw last time". This type of specific, actionable coaching is likely more effective than subjective commentary alone. This study highlights the need for residency curricula to explicitly address the risks of deep anesthesia with the same vigor as they address the risks of awareness. Simulation-based training, incorporating real-time BIS feedback on high-fidelity manikins, could allow residents to hone their titration skills in a safe environment before transitioning to the operating room.[18] The metrics used in this study, such as "percentage of time with BIS < 40" or "average post-induction BIS," could be incorporated into resident performance dashboards as an objective marker of progression toward competency.

While this study provides valuable insights, its limitations must be acknowledged to ensure a balanced interpretation. As discussed, the variable nature of supervision is the most significant limitation. While reflecting real-world practice, it means our results represent the performance of the resident-supervisor team, not the resident in isolation. The study was conducted at a single academic institution in Indonesia. Training philosophies, case mix, patient populations, and institutional culture can vary widely. Therefore, the specific shape and timeline of the learning curve observed here may not be directly generalizable to other training programs nationally or internationally. This study was not powered or designed to measure clinical outcomes like POD or length of stay.[20] While we discuss the potential risks associated with deep anesthesia based on existing literature, we cannot conclude that any patients in our cohort were harmed. The findings are of primarily educational, not clinical, significance. The cross-sectional design compares different residents at different stages, not the same residents followed over time. A longitudinal study, while more challenging to conduct, would provide a more definitive picture of individual learning trajectories.

This research opens several avenues for future investigation. The most critical next step is to conduct a prospective, randomized controlled trial to determine if incorporating routine, structured, BIS-based feedback into residency training can accelerate the learning curve and lead to measurable improvements in patient outcomes, such as reduced drug consumption and faster recovery times. Additionally, multi-center studies are required to establish the generalizability of our findings across diverse training environments.[21]

5. Conclusion

Anesthesiology residents demonstrate a clear, quantifiable learning curve in the management of anesthetic depth during the induction of general anesthesia. This progression is most evident not in the mean BIS values, but in the categorical distribution of hypnotic states, with junior residents exhibiting a significant tendency towards inducing unnecessarily deep levels of anesthesia. This finding highlights a critical educational target and a potential area for improving patient safety in academic medical centers. The Bispectral Index serves as a valuable, objective tool for mapping this learning trajectory, offering powerful possibilities for data-driven feedback, competency assessment, and the refinement of anesthesiology training curricula.

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