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Original Contribution

Training anesthesiology residents in providing anesthesia for awake craniotomy: learning curves and estimate of needed case load☆,☆☆

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Abstract

Study Objective: To measure the learning curves of residents in anesthesiology in providing anesthesia for awake craniotomy, and to estimate the case load needed to achieve a "good-excellent" level of competence.
Design: Prospective study.
Setting: Operating room of a university hospital.
Subjects: 7 volunteer residents in anesthesiology.
Measurements: Residents underwent a dedicated training program of clinical characteristics of anesthesia for awake craniotomy. The program was divided into three tasks: local anesthesia, sedation-analgesia, and intraoperative hemodynamic management. The learning curve for each resident for each task was recorded over 10 procedures. Quantitative assessment of the individual's ability was based on the resident's self-assessment score and the attending anesthesiologist's judgment, and rated by modified 12 mm Likert scale, reported ability score visual analog scale (VAS). This ability VAS score ranged from 1 to 12 (ie, very poor, mild, moderate, sufficient, good, excellent). The number of requests for advice also was recorded (ie, resident requests for practical help and theoretical notions to accomplish the procedures).
Main Results: Each task had a specific learning rate; the number of procedures necessary to achieve "good-excellent" ability with confidence, as determined by the recorded results, were 10 procedures for local anesthesia, 15 to 25 procedures for sedation-analgesia, and 20 to 30 procedures for intraoperative hemodynamic management.
Conclusions: Awake craniotomy is an approach used increasingly in neuroanesthesia. A dedicated training program based on learning specific tasks and building confidence with essential features provides "good-excellent" ability.

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1. Introduction

The introduction of new techniques or procedures in the practice of anesthesia requires specialized training [1,2]. Neuroanesthesia is a well-recognized subspecialty that requires specific knowledge, expertise, and training [3]. There is recent evidence that resection of brain lesions adjacent to speech areas with intraoperative real-time mapping during awake craniotomy allows more aggressive resection while minimizing perioperative morbidity [4,5]. Currently, awake craniotomy is the preferred approach to functional neurosurgery, including deep-brain stimulation for the treatment of Parkinson's disease and, more recently, the treatment of various other conditions, including obesity and severe obsessive compulsive disorders; epilepsy surgery; and any neurosurgical procedures that require intraoperative monitoring of speech and motor function [4–16].

From our experience and review of the literature, we identified three tasks essential to providing anesthesia for awake craniotomy: local anesthesia for scalp nerve blocks, sedation-analgesia, and intraoperative hemodynamic management [17]. A dedicated training program based on these three tasks was developed to train anesthesiology residents.

In this prospective study, we evaluated the learning curve of residents in anesthesiology for each of the three essential tasks needed for anesthesia for awake craniotomy. Evaluation of the learning curve was based on residents' self-assessment and attending anesthesiologist evaluations using a modified Likert scale and by recording the number of requests for advice or assistance. Based on the slope coefficient derived from learning curves, we also aimed to estimate the average number of cases needed to achieve a "good-excellent" level of competence for the related task.

2. Materials and methods

After "Sapienza" University of Rome Institutional Review Board review and approval (study No. 289/11, approved 10/3/2011 by Professor Isidori), 7 anesthesiology residents with at least two years of practice in neuroanesthesia were recruited to the study. Each patient in the study gave written, informed consent to participate. Basic requirements for resident participation in the training program were knowledge of neuroanesthesia principles, accepted practice of general anesthesia for craniotomy, and advanced expertise in airway management, including use of the Laryngeal Mask Airway and fiberoptic intubation [18–21].

2.1. Preliminary training

Residents received a dedicated training session that included formal presentation of the theoretical background, specific aims, needs, and risks related to each of the three tasks: local anesthesia for scalp block, sedation-analgesia, and intraoperative hemodynamic management [22]. The theoretical principles were taught in group discussion format, and ended with individual interviews to ensure that each resident achieved advanced understanding. Practical training was completed in small groups; two to three residents observed the same anesthetic for an awake craniotomy procedure, which included working under the guidance and direction of an experienced attending anesthesiologist during at least 10 procedures. When residents had direct responsibility of managing the procedure, the attending anesthesiologist remained on site to monitor the procedure, provide advice when required, and take over the case if needed.

Local anesthesia was administered during awake craniotomies with the aim of blocking scalp sensory stimuli and was accomplished with a total of 0.5 mL/kg (of patient's body weight) 7.5% ropivacaine for selective blocks of sensory branches of the trigeminal nerve (auricolotemporal, zygomaticotemporal, supraorbital, supratrochlear) and of the greater and lesser occipital nerves. Furthermore, the head holder pin sites and surgical skin incision line also were infiltrated with subcutaneous injection of local anesthetics [23–25].

The sedation-analgesia protocol used at our institution primarily relies on propofol-fentanyl or propofol-remifentanil infusion; droperidol and an α2-receptor agonist are also used when needed [26,27]. Furthermore, this task encompasses aggressive prevention and treatment of postoperative pain. Paracetamol (1 gr x 3/day) was the mainstay of systemic postoperative analgesic therapy. Opioids (morphine or fentanyl) were added in patients with persistent pain or in whom paracetamol was contraindicated [28].

Intraoperative hemodynamic management was used to manipulate the systemic and cerebral hemodynamics so as to guarantee optimal brain perfusion and surgical field conditions [29,30]. This task encompasses the use of various antihypertensive medications to lower arterial blood pressure when needed, including short-acting and long-acting beta blockers (esmolol, metoprolol or labetalol), calcium-channel antagonists (diltiazem), the α1-adrenoceptor antagonist (urapidil), and the α2-receptor agonist (clonidine) [31–34]. The use of nitrates was discouraged because of the related increase in cerebral blood volume and significant brain swelling [35,36]. Ephedrine was considered as a first-choice therapeutic approach for the treatment of bradyarrhythmias and arterial hypotension, while isoprenaline use was indicated in bradyarrhythmias associated with arterial hypertension. Atropine use was discouraged due to related drawbacks such as facilitation of seizures and postoperative delirium [37]. Perioperative tachyarrhythmias may be caused by various pathophysiological mechanisms and treatment should be addressed to the underlying cause, which may include hypovolemia, anemia, pain, or increased sympathetic tone. In the latter case, beta blockers are the preferred drugs [34].

Perioperative monitoring for all patients included continuous three-lead echocardiogram for heart rate and arrhythmias monitoring, invasive arterial catheter for real-time systolic, diastolic, and mean arterial pressures, oxygen saturation via pulse oximetry (SpO_2), nasal end-tidal CO_2, and urine output.

2.2. Evaluation of the learning curve

Residents' learning curves were evaluated over 10 procedures. Quantitative assessment of the individual's ability was based on the resident's self-assessment score and the attending anesthesiologist's judgment score, and rated according to a 6-rank, 12-cm, modified Likert scale reported ability score visual analog scale (VAS): very poor (1-3 cm), mild (3-4 cm), moderate(4-6 cm), sufficient (6-8 cm), good (8-10 cm), and excellent (10-12 cm) [38]. Learning curves were drawn based on self-assessment and attending anesthesiologists' scores by plotting graphically the mean value for each procedure. The number of requests for advice also was recorded.

To assess the quality of the surgical field, tactile evaluation of intraoperative dural tension was scored with a 4-point scale (1=very slack, 2=normal, 3=increased tension, and 4=pronounced increased tension) and cerebral swelling after dural opening was scored with 3-point scale (1=no swelling, 2=moderate swelling, and 3=pronounced swelling) and were estimated by the neurosurgeon [39,40].

Postoperative patient satisfaction was evaluated using the "Iowa Satisfaction with Anesthesia Scale" (ISAS) at 24 hours after surgery [41,42]. According to this scale, patients evaluate 11 statements, selecting a score from -3 to +3 for each item; the total score ranges between -33 and +33 (from lowest values -33 to a completely satisfied pt who would score +33).

2.3. Statistical analysis

Data were coded and entered into a dedicated database. The mean ± standard deviation (SD) value was calculated for each task over the 10 procedures for the 7 residents. As the sums of the responses were not normally distributed, a nonparametric analysis was done by Friedman's test, a nonparametric nondistribution-dependent test, and used to assess score differences at each attempt. A P-value < 0.05 was considered significant to reject the null hypothesis that subsequent attempts were not associated with an improvement in the learning process (univariate analysis).

To describe the trend of the learning curves, the interpolated lines and the related slope coefficients were calculated by applying regression analysis using the least squares technique for each task. The interpolated lines assume the form $\alpha y = \beta x + c$, where β/α = the attenuation slope coefficient that indicates the line's inclination, and c/α = a constant that indicates the starting value. To assess adherence of the interpolated line to the recorded data, the coefficient R^2 was also calculated for each interpolated line. The R^2 coefficient indicates the distance between the measured values and the calculated interpolated line. To build a model to predict the number of procedures needed to obtain a "good-excellent" VAS score in 95% of residents, we used the least squares-derived interpolated lines for each of the three tasks (assuming that the learning process is linear). To further confirm results obtained by least squares-derived interpolated lines, we also calculated logistic ordinal regression and confidence intervals (CIs).

For each task we also calculated the estimate slope of the curve (standardized slope coefficient) and the effect likelihood ratio test so as to verify the goodness-of-fit between two models. The logistic model was considered statistically better when $P < 0.05$.

Internal consistency for ISAS values was measured by Cronbach's alpha.

3. Results

All 7 anesthesiology residents, 5 men and two women, completed the training program over a period of three years. In the recorded cases, no resident reported a "failure" in clinical management. Demographics and clinical characteristics of the study patients are summarized in Table 1.

3.1. Learning curve for local anesthesia

The mean ability score for accomplishing local anesthesia during the first procedure was "poor," as consistently recorded by both residents' self-assessment and attending anesthesiologists' judgment (2.1 ± 0.7 and 1.8 ± 0.7; Figs. 1, 2). Despite the "poor" ability during the initial procedures, the learning curve for local anesthesia showed a rapid progression, and at the tenth procedure the mean score achieved an "excellent" value (11.4 ± 1.1 in the self-assessment and 10.8 ± 0.8 in the attending anesthesiologists' judgment; Figs. 1, 2). The Friedman's test confirmed a positive relationship between the number of attempts and the improvement in providing

Table 1 Demographic and clinical characteristics of the study patients

Patients (n)	Age (yrs)	Gender (M/F)	ASA physical status	Arterial hypertension	COPD	Diabetes mellitus Type II
70	55 ± 7	43/27	2 - 3	31	9	21

COPD=chronic obstructive pulmonary disease.

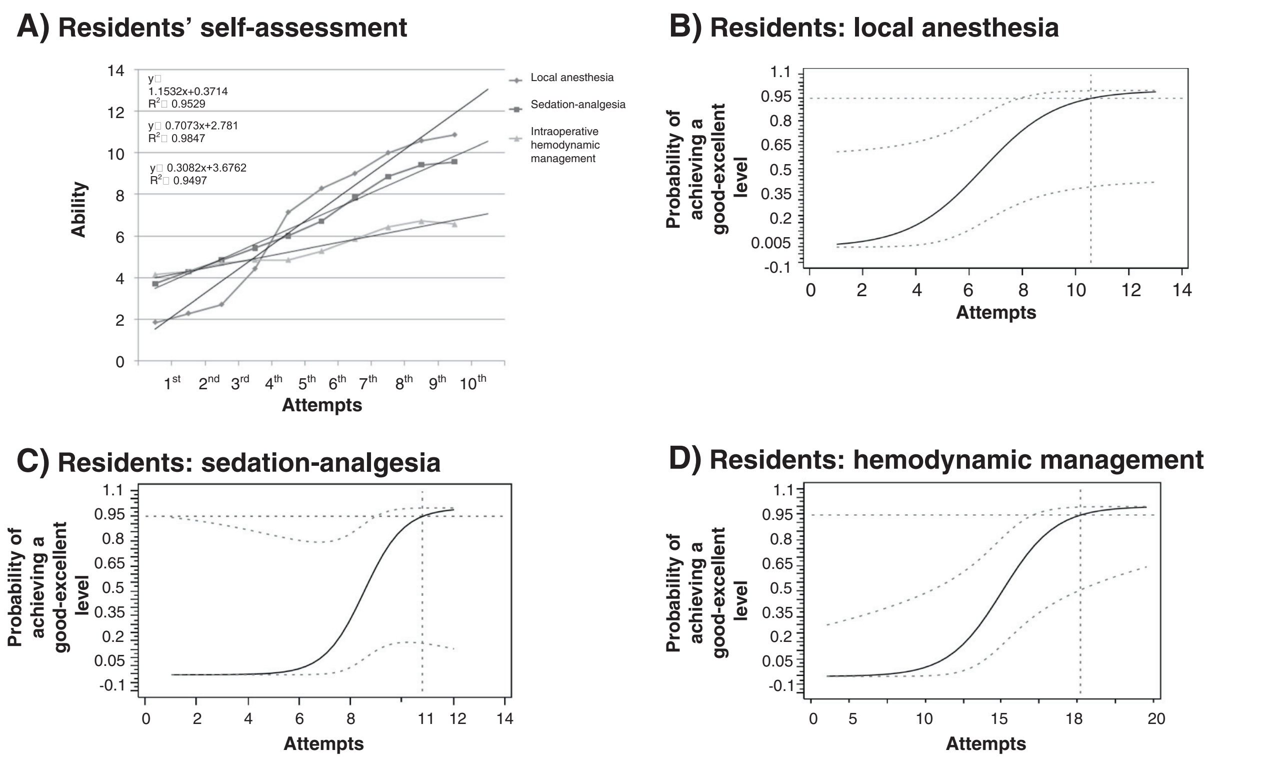

Fig. 1 (A) Residents' self-assessment least squares interpolated lines and logistic regression plots. Learning curves derived by residents' self-assessment scores for the three tasks needed in awake craniotomy: (B) local anesthesia, (C) sedation-analgesia, and (D) intraoperative hemodynamic management. The mathematical description (equation of the line) of the interpolated line (y) was obtained by adding the slope coefficient to the mean value at the first procedure (y-intercept), and the coefficient R^2, which = the distance between the measured values and the calculated interpolated line.

local anesthesia (P < 0.001). The fast-rate progression in learning this task was confirmed by the slope coefficient of the interpolated line that suggested an average increase in ability score of 1.1 ± 1.4 (Table 2). Although slope coefficient is an inference measure derived by the interpolated line, considering the tight relation between the interpolated line and the source data in this setting (R^2 = 0.95 for the self-assessment and R^2 = 0.96 for the attending anesthesiologist judgment; Figs. 1, 2), it reliably represents the actual trend in learning progress for this task. The slope coefficient of 1.1 suggested that an average training experience of 10 procedures should be adequate to achieve a "good to excellent" ability score. The logistic ordinal regression model, used to estimate the number of procedures necessary to obtain a "good-excellent" VAS score in local anesthesia for 95% of the residents, confirmed that the last number of procedures needed was more than > 8.7. The standardized slope coefficient was 1.29 and the effect likelihood ratio test was associated with a statistically significant goodness-of-fit of the logistic model (P < 0.0037).

The reduction of advice requests recorded over the 10 procedures further confirmed progress in the learning process (Fig. 3). The curve fitting suggested that an average training experience of 11 procedures was adequate to achieve a reduction of advice requests to 0 in 95% of residents.

3.2. Learning curve for sedation-analgesia

The mean ability score for accomplishing sedation-analgesia during the first procedure was "mild," consistently recorded by both residents' self-assessment and attending anesthesiologist's judgment (3.7 ± 0.9 for both; Figs. 1, 2). The learning curve for sedation-analgesia showed good progression and at the tenth procedure the mean score achieved a "good" value (9.5 ± 0.7 in self-assessment and 9.7 ± 0.9 in attending anesthesiologist's judgment; Figs. 1, 2). The Friedman's test confirmed a positive relationship between the number of attempts and the improvement in providing sedation analgesia (P < 0.001). The good-rate progression in learning how to provide sedation-analgesia was confirmed by the slope coefficient of the interpolated line, which suggested an average increase in ability score of 0.7 ± 0.9 for each procedure and reliably represented the trend in the learning progress for this task (R^2 = 0.98; Table 2; Figs. 1, 2). The slope coefficient of 0.7 suggested that an average training experience of 15 to 25 procedures was adequate to guarantee the achievement of a "good to excellent" ability score. The logistic ordinal regression model, used to estimate the number of procedures necessary to obtain a "good-excellent" VAS score in sedation analgesia

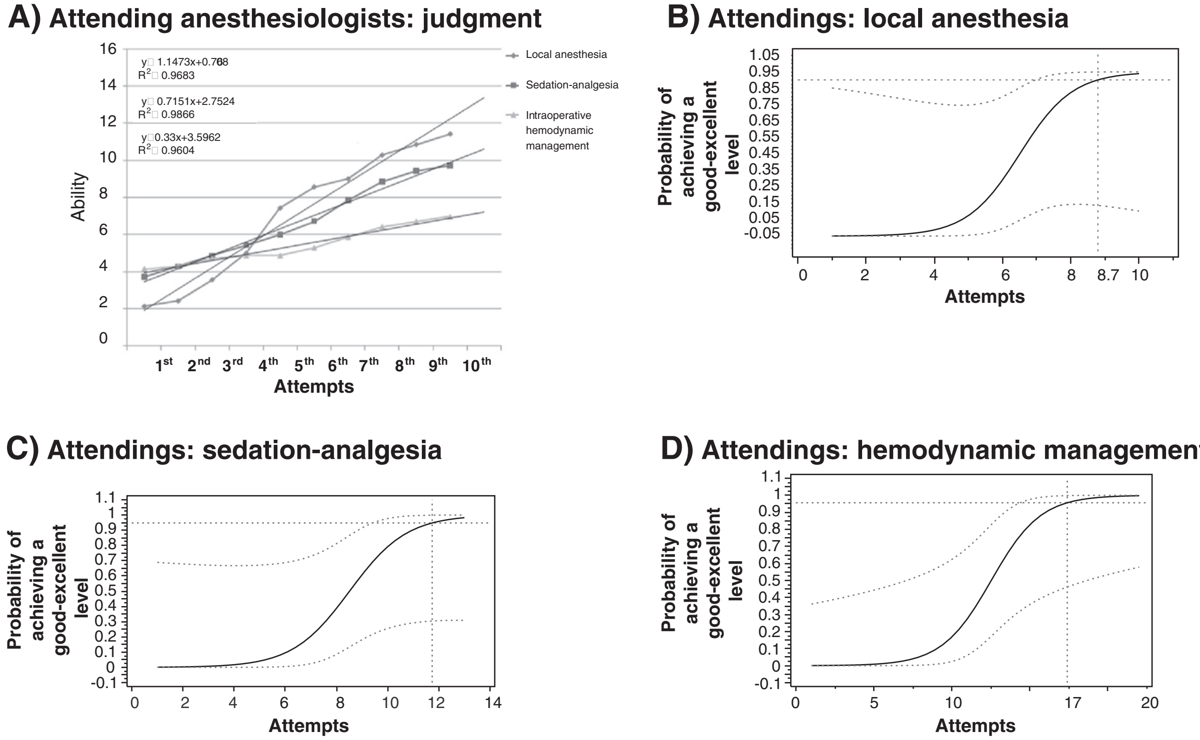

Fig. 2 (A) Attendings' self-assessment least squares interpolated lines and logistic regression plots. Learning curves were derived by attending anesthesiologists' judgement scores for each of the three tasks necessary for awake craniotomy: (B) local anesthesia, (C) sedation-analgesia, and (D) intraoperative hemodynamic management. The mathematical description (equation of the line) of the interpolated line (y) was obtained by adding the slope coefficient to the mean value at the first procedure (y-intercept), and the coefficient R^2, which = the distance between the measured values and the calculated interpolated line.

for 95% of the residents, confirmed that the least number of procedures needed was >12. The standardized slope coefficient was 0.89 and the effect likelihood ratio test was associated with a statistically significant goodness-of-fit of the logistic model ($P < 0.0014$).

The reduction of advice requests recorded over the 10 procedures further confirmed progress in the learning process (Fig. 3). The curve fitting suggested that an average training experience of 13 procedures should be adequate to achieve a reduction of advice requests to 0 in 95% of residents.

3.3. Learning curve for intraoperative hemodynamics management

The mean ability score for accomplishing intraoperative hemodynamic management during the first procedure was "mild to moderate," consistently recorded by both residents' self-assessment and attending anesthesiologist's judgment (4.1 ± 0.7 for both; Figs. 1, 2). The learning curve for intraoperative hemodynamic management showed slow progression and at the tenth procedure the mean score achieved a "sufficient" score (6.9 ± 1.3 for both self-assessment and the attending anesthesiologist's judgment; Figs. 1, 2). The Friedman's test confirmed a positive relationship between the number of attempts and improvement in providing hemodynamic management ($P < 0.014$). The slope coefficient of the interpolated line suggested an average increase in ability score of 0.3 ± 0.4 for each procedure and reliably represented the trend in the learning progress for this task ($R^2 = 0.94$ for the self-assessment and $R^2 = 0.96$ for the attending anesthesiologist's judgment; Table 2; Figs. 1, 2). The slope coefficient of 0.3 suggested that an average training program of 20 to 30 procedures should be adequate to guarantee the achievement of a "good to excellent" ability score. The logistic ordinal regression model, used to estimate the number of procedures necessary to obtain a "good-excellent" VAS score in sedation analgesia for 95% of the residents, confirmed that the last number of procedures needed was >17. The standardized slope coefficient was 0.6 and the effect likelihood ratio test was associated with a statistically significant goodness-of-fit of the logistic model ($P < 0.001$).

The persistently high number of requests for advice recorded over the 10 procedures further confirmed slow progress in the learning process (Fig. 3). The curve fitting suggested that an average training experience of 18 procedures should be adequate to achieve a reduction of advice requests to 0 in 95% of residents.

Table 2 Slope coefficients for the three tasks assessed

	Local anesthesia	Sedation - analgesia	Intraoperative hemodynamic management
Residents' self-assessment	1.1 ± 1.4	0.7 ± 1.0	0.3 ± 0.5
Attending anesthesiologist's judgement	1.1 ± 1.5	0.7 ± 0.9	0.3 ± 0.3

The interpolated line of the learning curves was obtained from residents' self-assessment and the attending anesthesiologist's judgment of ability scores. The slope coefficient value is related to the steepness of the interpolated line, and represents the progression in the learning curve: mean ability score improvement per procedure.

3.4. Surgical field conditions and patient's satisfaction postoperatively

Mean dural tension and brain swelling did not change over time (from 2.7 ± 0.7 to 1.8 ± 0.3 and from 1.2 ± 0.4 to 1.1 ± 0.3), nor did patient's satisfaction postoperatively (ISAS mean score from +30.7 ± 1.7 to +32.1 ± 1.2).

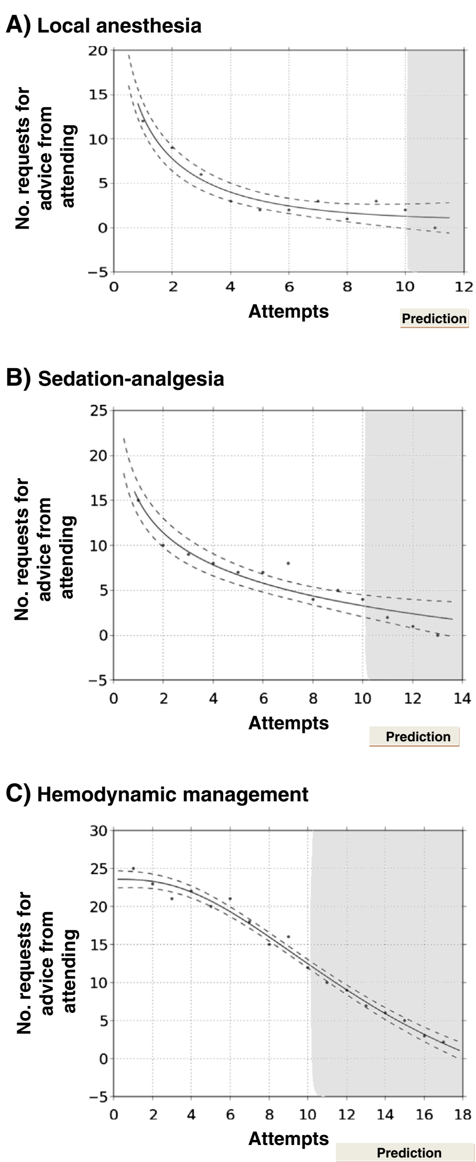

Fig. 3 Bar plot of the number of requests for advice by the 7 residents over the 10 procedures for (A) local anesthesia, (B) sedation, and (C) hemodynamic management.

4. Discussion

In this prospective study, we reported the learning curves of anesthesiology residents for three tasks that characterize anesthesia for awake craniotomy. Our results showed that each task was related to a specific learning progression. Therefore, after adequate theoretical and practical training a specific number of procedures should be planned for each task to achieve a "good to excellent" ability score. Furthermore, a different amount of training is necessary for the individual tasks to achieve the same level of proficiency. The learning curves we have recorded in this study apply for the academic environment and for the anesthesia procedure specifically selected in the study, and may differ when alternative techniques, such as asleep-awake-asleep with intermittent control of the airways, are used.

Several papers have addressed the need for a structured program to provide anesthesia during awake craniotomy [10,17,19–21,25,26,43,44]. Among the main challenges for such a program are adequate local anesthesia, the ability rapidly to adjust the level of sedation and analgesia according to surgical events, and ensuring hemodynamic stability, adequate ventilation, and minimal interference with electrophysiological recordings. Several other factors, such as patient selection and optimal intraoperative neurocognitive testing, play a key role in accomplishing a successful awake craniotomy [45–47]. To evaluate and optimize the training process, we designed a dedicated training program based on three factors [17].

Local anesthesia (for scalp block, pin placement, and surgical incision line) is a cornerstone needed to accomplish anesthesia for awake craniotomy. Our results suggested that although the initial mean ability score for this task was the lowest among the three tasks assessed, perhaps because of the lack of confidence with a new procedure, progression was fastest.

Sedation and analgesia have a key role in delivering "anesthesia" for awake craniotomy since oversedation might lead to an uncooperative patient and cause respiratory depression, undersedation makes patients uncomfortable and agitated and is frequently complicated by hemodynamic instability (especially arterial hypertension and tachycardia). Adequate sedation may result in a less physically and emotionally stressful awake anesthesia than general anesthesia [24,44].

Intraoperative management of hemodynamics should be addressed to manipulate systemic and cerebral perfusion pressure so as to guarantee optimal brain perfusion and surgical field conditions [29,30]. Hemodynamic manipulation encompasses aggressive treatment of intraoperative and postoperative arterial hypertension, thus minimizing the risk of postoperative intracranial bleeding, and arrhythmias (both tachyarrhythmias and bradyarrhythmias) [23,31–33]. In the setting of anesthesia for awake craniotomy, the use of anesthetics is strictly limited; therefore, drugs primarily used for cardiovascular purposes, including vasoactive and anti-arrhythmic drugs, should be selected according to the specific need. We interpreted the slow progression of the learning curve for this task as the result of residents' limited confidence with cardiovascular drugs.

The teaching evaluation method we used was based on self-assessment and evaluation by a "referee" (the attending anesthesiologist); we also recorded the advice requested. Although there is no consensus as to appropriate measures for evaluating training abilities, we consider this approach reliable and informative [18,22,38].

4.1. Study limitations

In comparison to other studies, our study evaluated a relatively small number of trainees and a small number of procedures [18,24]. Nevertheless, we consider the information we have drawn from our experience reliable because all of the trainees were relatively experienced in neuroanesthesia and had received prior neuroanesthesiology training before being exposed to the anesthesia for awake craniotomy training program. A second limitation of this study was that only two of the 7 evaluated residents (< 30%) were women, in spite of the fact that most of the residents in our program are women (about 60%), thereby introducing a gender bias. Another limitation was related to the potential bias due to sequential assessment, both for self-assessment (since trainees are likely to report an improvement with repeated experiences) and assessment from supervising staff (staff members were necessarily not blinded to the experience of residents). A fourth limitation was that dexmedetomidine was not included in the sedation-analgesia protocol, as it is not yet available in Italy. The use of dexmedetomidine has been proposed for "anesthesia" for awake craniotomy, with or without concurrent use of propofol to provide sedation without respiratory depression [48].

In conclusion, anesthesia for awake craniotomy is a demanding technique that requires specific skills, adequate patient selection, and close interaction between anesthesiologist, neurosurgeon, and patient. A dedicated training program based on the specific tasks needed for this procedure, and confidence with several prerequisites, including previous experience with general anesthesia for craniotomy and advanced expertise in airway management, produces "good-excellent" ability and self-confidence in accomplishing this procedure.

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