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Assessment of the learning curve of video-assisted thoracoscopic sympathectomy in a single neurosurgical trainee: a cumulative summation analysis

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Abstract

Background: Video-assisted thoracoscopic sympathectomy (VATS) is a common procedure unusually practiced by neurosurgeons due to lack of training.

Objective: To evaluate the learning curve for VATS in a young neurosurgeon with no previous experience in open sympathectomy techniques or extracranial endoscopic procedures.

Methods: This is a retrospective review and analysis of prospectively collected data in 50 consecutive cases admitted to our facility with the diagnosis of essential palmar and axillary hyperhidrosis operated by a neurosurgical trainee under strict supervision of 2 experienced mentors. After an initial training phase, cumulative summation (CUSUM) analysis was used to evaluate the surgical performance of the trainee in terms of operating time, blood loss, hospital stay and failures.

Results: Improvement in operating time was noticed after the first 20 cases with significant affection by changes in OR team. The blood loss was significantly improved after the first 10 cases with less sensitivity to changes in OR team. Hospital stay and failures were steady and within expected values throughout the study.

Conclusion: An average of 20 cases may be enough for a neurosurgeon with basal knowledge to attain technical competence in VATS sympathectomy. Mentored surgical training on VATS sympathectomy is a safe and effective training method with failures within expected limits. The experience of the OR team plays an important role in the rapid improvement and consistency of performance.

Keywords: Learning curve, Sympathectomy, Cumulative sum, Thoracoscopy

Introduction

Since its first performance in 1889 [1], surgical sympathectomy has been evolving over years. Several early uses of sympathectomy [1–9] were discarded, rendering others as current indications [10–15], primarily palmar hyperhidrosis. Parallel to this, an evolution in techniques

started by perivascular sympathectomy [16, 17] and nervous fascicular dissociation [18], followed by gangliectomy [19], diathermy ablation [20], radiofrequency [21] and clipping [22]. Thoracic sympathectomy was initially approached by classic posterior [23, 24], supraclavicular [25], anterior transthoracic [20, 26] and transaxillary approaches [27]. However, minimally invasive sympathectomy introduced by Hughes [28] then Kux [29] supplanted all these techniques and became the standard technique for upper thoracic sympathectomy [30].

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Despite being commonly performed by thoracic and vascular surgeons; video-assisted thoracoscopic sympathectomy (VATS) is rarely practiced by neurosurgeons who favor open sympathectomy or case referral because of anatomical unfamiliarity and lack of training. The aim of this study was to evaluate the learning curve for VATS in a young neurosurgeon with no previous experience in open sympathectomy techniques or extracranial endoscopic procedures.

Methods

Study design

Cumulative summation (CUSUM) analysis of a case series of video-assisted thoracoscopic sympathectomy (VATS) for essential hyperhidrosis operated by a neurosurgical trainee mentored by the authors.

Mentors and trainee

The authors mentored a neurosurgical resident with no experience in sympathectomy or extracranial endoscopic procedures to evaluate the learning curve of VATS in trainees with basal knowledge. An initial 2-staged “training phase” was conducted. During the first stage, the trainee read 10 most-relevant articles and watched 20 demonstrated video clips of VATS performed by mentors. In the second stage the trainee got evaluated as an assistant using a (0–10) scale in several VATS procedures. The evaluation score was the mean score by both mentors or the evaluation score of the only attending mentor. When the trainee achieved an acceptable level of orientation, he started a “practice phase” in which he performed 100 VATS procedures, bilaterally in 50 consecutive cases with essential hyperhidrosis under strict supervision of the mentors. During the procedures, no intervention was performed by mentors except in near misses or when the trainee faced a technical challenge or a complication. A note or advice given by the mentor was considered a minor intervention, while manual control or taking over by the mentor was a major intervention.

Patients

Between August 2015 and October 2018 following approval of local IRB, 50 consecutive cases with essential palmar and axillary hyperhidrosis were included after giving informed written contents and excluding secondary hyperhidrosis. All demographic, clinical and operative data was collected prospectively. Hyperhidrosis was severe (score 3 or 4) according to Hyperhidrosis Disease Severity Scale (HDSS) [31]. All patients tried unsuccessful non-operative management for variable durations. Patients were 15 years or older to suit the telescope size and ports in the endoscopic setup.

Operative and postoperative methods

Patients were operated under general anesthesia using HOPKINS® II forward-oblique telescope 30°, provided by KARL STORZ® SE & Co. KG, Tuttlingen, Germany. The surgical details of thoracic sympathectomy was described by the authors elsewhere [13]. Electrocautery ablation of the third and the fourth thoracic sympathetic ganglia were performed for palmar and axillary hyperhidrosis. Blood loss was estimated in mls; including blood collected in suction device and that in used surgical gauzes. Blood volume in soaked gauzes was calculated as the difference in weight between pre-used gauzes and those immediately discarded from the surgical field; then substituting 1 ml for every 1 g increase in weight [32]. Weight measurements were performed using Digi DS-673SS Waterproof Swab Scale with 1 g graduations. The duration of surgery was defined as the time passed between the first skin incision and last skin suture using a digital stopwatch controlled by the anesthetist. Following surgery, patients were transferred to the recovery room for at least 1 h for monitoring of vital signs and ensuring equal air entry until full recovery. Oral fluids were allowed once patients became alert. After 3 h, a plain chest X-ray was performed. Postoperative pain was controlled without narcotic analgesics using IV paracetamol or/and IM NSAIDs. At 6 h, postoperative pain was estimated using a 0–10 Numeric Pain Intensity Scale (NPIS) in all patients. Patients were discharged on the same day of surgery unless they were hemodynamically unstable, having $SO_2 < 95\%$, showing abnormality on chest X-ray or pain scores of 5 or more. These abnormalities indicated longer hospitalization for stabilization.

Outcome measures

Early outcome (2 weeks after surgery) was evaluated by the improvement rate in sweating. Improvement rate was estimated as: $(\text{Preoperative HDSS} - \text{postoperative HDSS}) / \text{preoperative HDSS} \times 100$. Short-term outcome (at 3 months) was evaluated using Hyperhidrosis Quality-of-Life Questionnaire (HQLQ) [33]. Complications were either; technique- or procedure-related. Technique-related complications as: intercostal neuralgia, Horner's syndrome, injury to an intrathoracic structure, incision-related complications, hemo- or/and pneumothorax and surgical emphysema were considered, while procedure-related complications like bradycardia, excessive hand dryness and compensatory sweating were excluded; being undesirable effects of sympathectomy rather than related to the learning curve. Technique-related complications were classified as minor or major complications according to Clavien and his colleagues [34]. Failures included: “technical failures” like major intervention by the mentor,

conversion to open thoracotomy and technique-related major complication; and/or “outcome failures” like improvement rates $\leq 50\%$ in early outcome assessment and/or HQLQ scores more than 51 at 3-month.

Statistical analysis

The learning curve was quantitatively assessed using cumulative summation (CUSUM) analysis of the following parameters: operating time (OT), estimated blood loss (EBL), length of hospital stay and failure. The CUSUM charts for continuous data were introduced by Page [35] to address small shifts of the tested parameter and to monitor its deviation from a target value. Analysis of the binary outcome (success vs. failure) was presented by cumulative log-likelihood ratio chart, adapted from Rogers and colleagues [36].

After testing normality by Shapiro–Wilk test, continuous data was described in mean \pm SD or in median and IQR. Categorical data was described as numbers and percentages. Continuous data was compared using unpaired Student *t* test when normally distributed or using Kruskal–Wallis and Mann–Whitney tests when not normally distributed, while categorical data was compared using Chi-Square test. Data was analyzed using IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp., 2011 and curves were created by Microsoft Excel 2010 with QI Marcos add-in.

Results

The timeline of study and evaluation scores of the trainee are presented (Figs. 1 and 2, respectively). The demographic data of patients are presented in Table 1. The operating time ranged from 11 to 42 min/procedure (median of 16 and IQR of 7 min). Initially, the CUSUM curve showed sharp upward drift exceeding the upper CUSUM line (out-of-control process) followed by a noticeable downward trend to reach below the upper CUSUM line by the 15th procedure. However, at the 39th procedure (20th case) the curve showed again a sharp

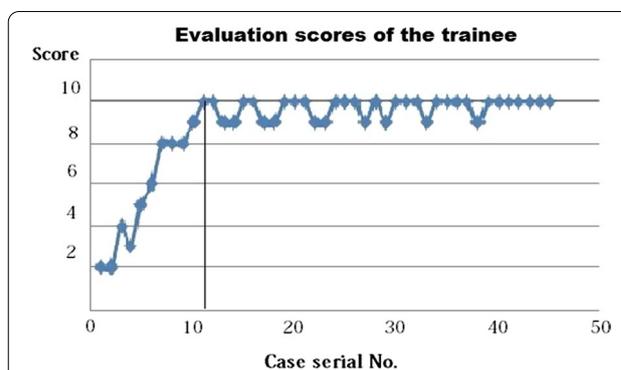


Fig. 2 A relatively steep curve of the evaluation scores of the trainee during training phase with a plateau at the 10th case, revealing a rapid acquisition of anatomical and setup orientation. The score ranged between 2 and 10 with an overall mean of 8.8

upward trend to reach above the upper CUSUM line. This was coincidental with the shift of procedures from vascular to neurosurgical operating theater because of technical challenges. By the 44th procedure, the curve crossed again the upper CUSUM line downward to reach a steady state and remained fluctuating randomly around the zero line till the end of the study (Fig. 3).

The EBL ranged from 10 to 74 ml/procedure (median of 14 and IQR of 10 ml). Initially, the curve drifted sharply above upper CUSUM line, then showed a downward trend to cross the control line at the 23rd procedure and flattens by the 27th. Similarly, the curve again deflected upward at the 39th procedure when the OR team was replaced, but unlike in CUSUM of operating time; the curve of EBL remained under the upper CUSUM till its downward slope again by the 42nd procedure to reach a steady state till end of analysis (Fig. 4).

Patients spent 0–3 nights inside the hospital following surgeries (Table 2). The CUSUM curve showed expected hospital stay during first 12 cases where the curve, although not steady, was running between upper and lower limits. In the cases 14 and 15 the curve spiked

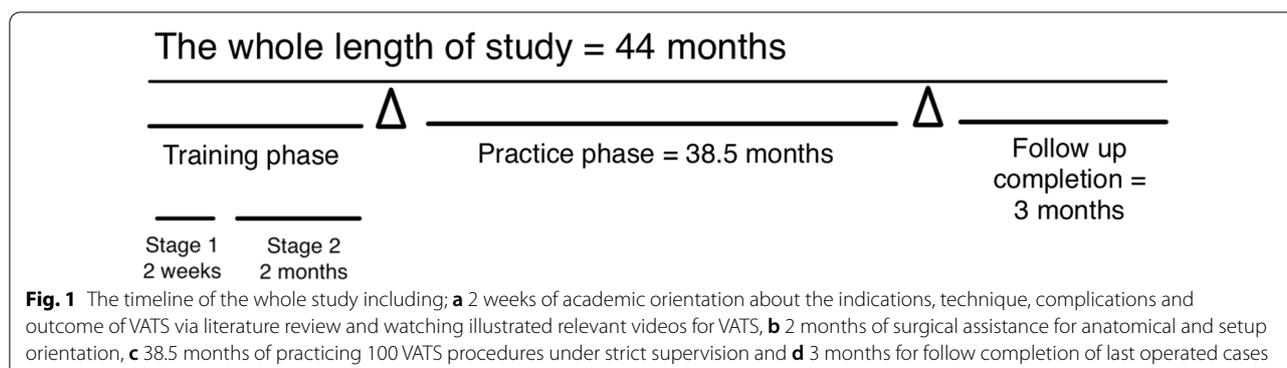


Fig. 1 The timeline of the whole study including; **a** 2 weeks of academic orientation about the indications, technique, complications and outcome of VATS via literature review and watching illustrated relevant videos for VATS, **b** 2 months of surgical assistance for anatomical and setup orientation, **c** 38.5 months of practicing 100 VATS procedures under strict supervision and **d** 3 months for follow completion of last operated cases

Table 1 Demographic data of patients in the study

	Total	Females	Males	<i>p</i> value	Statistical test
Number (%)	50 (100%)	32 (64%)	18 (36%)		
Mean age	18.9 (2.7)	18.1 (2.5)	20.3 (2.5)	0.005	Independent samples <i>T</i> test
Mean BMI (SD)	25 (2.6)	26.1 (1.9)	23.1 (2.5)	< 0.001	Independent samples <i>T</i> test

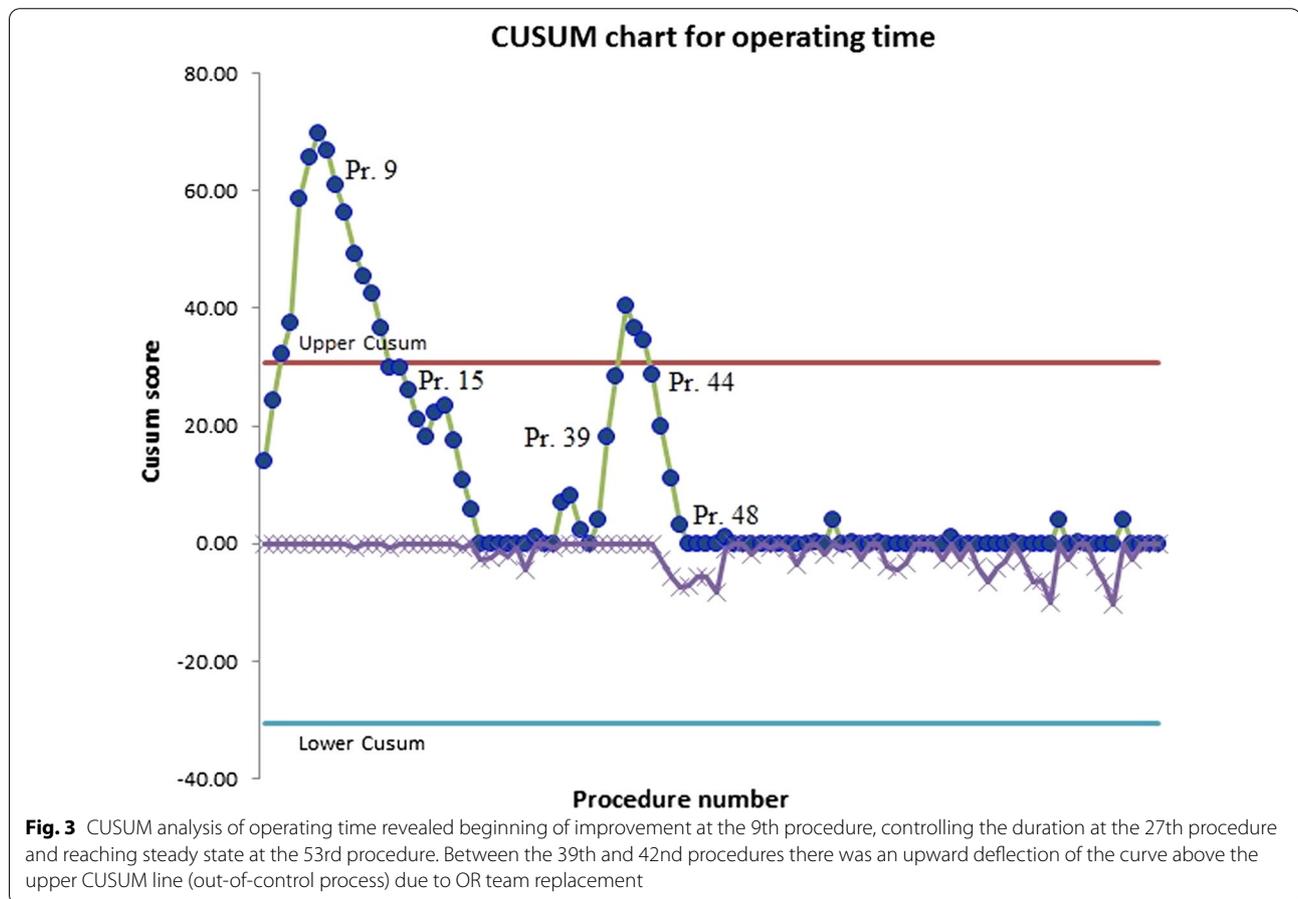


Fig. 3 CUSUM analysis of operating time revealed beginning of improvement at the 9th procedure, controlling the duration at the 27th procedure and reaching steady state at the 53rd procedure. Between the 39th and 42nd procedures there was an upward deflection of the curve above the upper CUSUM line (out-of-control process) due to OR team replacement

above the upper limit indicating that the cumulative nights of stay was out-of-control. However, from case 16 progressive improvement was noted and the process became under control till a flat curve was reached at the 20th case (Fig. 5). Four cases (8%) were reported as failures in this study (Table 3). Persistent intercostal neuralgia was reported as a cause of failure in two cases and were managed in pain clinic by periodic intercostal nerve blocks. The CUSUM graph for failure fluctuated randomly around central line within the upper and lower CUSUM limits indicating within expected performance (Fig. 6).

The procedures were split into 5 groups; 20 successive procedures each. The groups were compared regarding

operative time, EBL, hospital stay and outcome. The operative time dropped significantly after the second group ($p=0.003$), indicating a significant improvement in operative time following the first 40 procedures (20 cases). On the other hand, the EBL showed a reduction after the first 20 procedures ($p=0.002$). In contrary, the hospital stay and outcome showed no significant difference between groups (Kruskal–Wallis, $p=0.235$ and Pearson Chi-square, $p=0.695$, respectively).

Discussion

The CUSUM technique is a sequential analysis that permits an observer to decide whether the performance variation within or beyond the expected random variation to

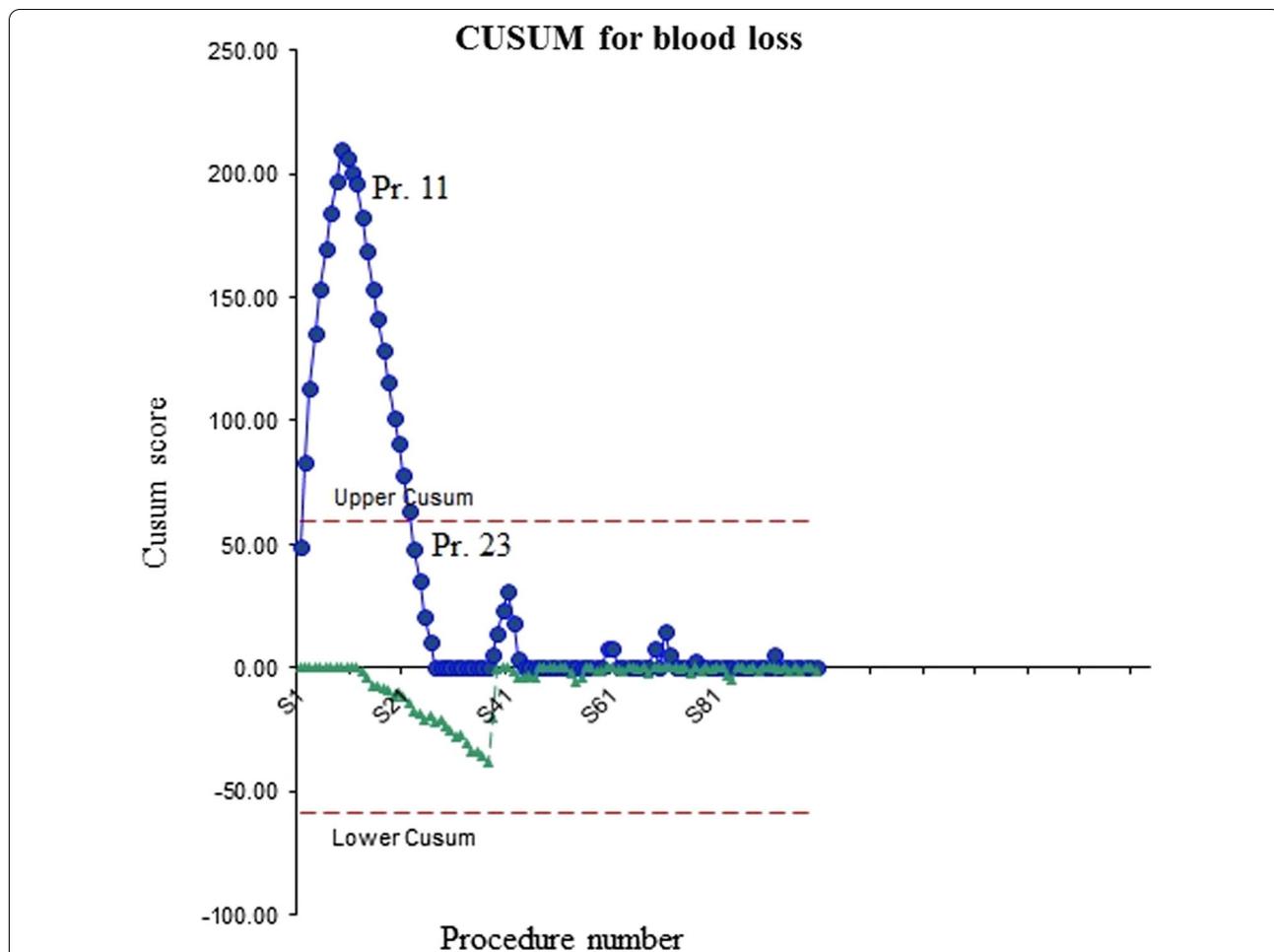


Fig. 4 CUSUM analysis of estimated blood loss (EBL); shows improvement of hemostasis by the 13th procedure, full control by the 29th procedure and proficiency at the 45th procedure

Table 2 Length of hospital stay and postoperative conditions

Number of cases	Length of stay	Postoperative status	Chest radiography	Management
1 case	3 nights	Unilateral moderate (6/10) chest pain Mild dyspnea on exertion with SO ₂ 94% Hemodynamically stable	Minor pneumothorax ipsilateral to the side of pain	Conservative management using IV paracetamol + IM NSAIDs + O ₂ supply. Resolution at 36 h
1 case	2 nights	Bilateral chest pain (5/10) Mild dyspnea on exertion with SO ₂ 96% Hemodynamically stable	Negative	Conservative management using IV paracetamol + IM NSAIDs + respiratory exercises
1 case	2 nights	Unilateral chest pain (5/10) No dyspnea Hemodynamically stable	Negative	Conservative management using IM NSAIDs
9 cases	1 night	Unilateral/bilateral chest pain (5 and 6/10) No dyspnea Hemodynamically stable	Negative	Conservative management using IM NSAIDs
38 cases	< 1 night	Negligible chest pain (2–4/10) No dyspnea Hemodynamically stable	Negative	1 gm of IV paracetamol

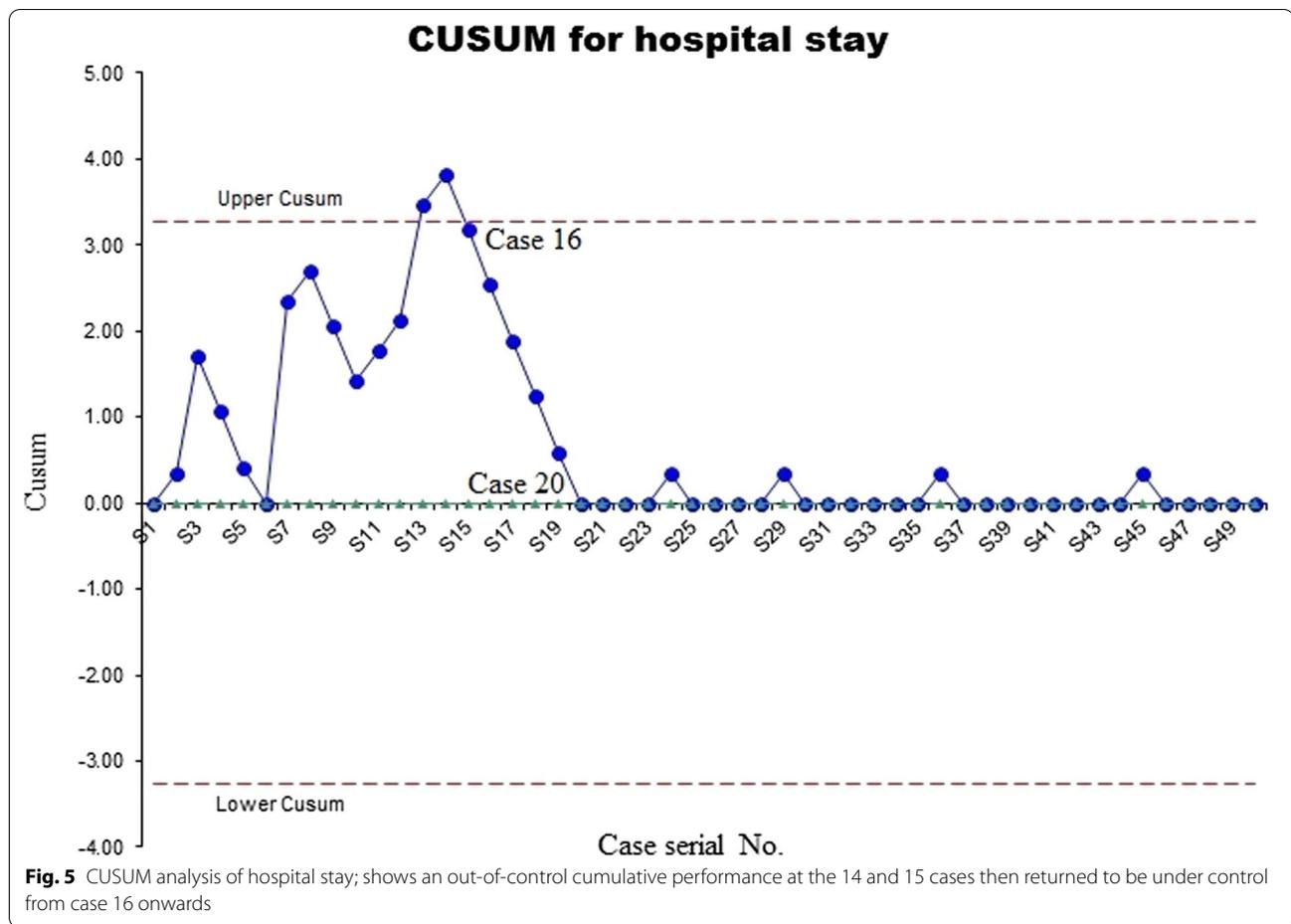


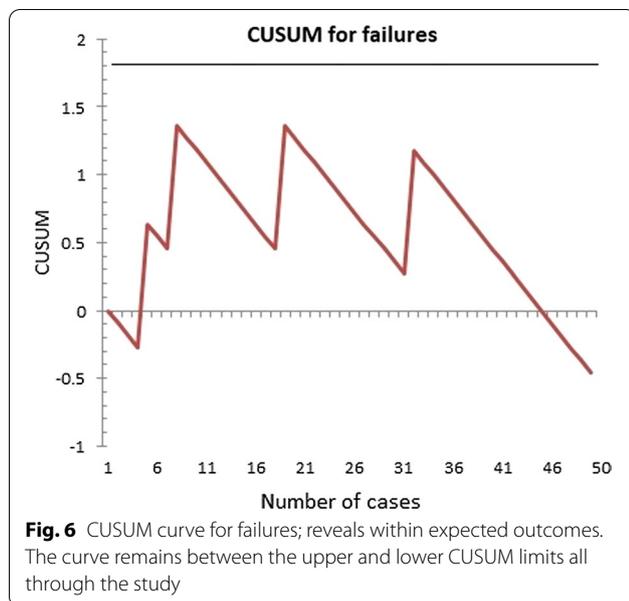
Fig. 5 CUSUM analysis of hospital stay; shows an out-of-control cumulative performance at the 14 and 15 cases then returned to be under control from case 16 onwards

Table 3 Procedures with reported failures during the study

Procedure no	Type of failure
Case 5	Major intervention by the mentor (both sides; due to adhesions) Persistent intercostal neuralgia (left side) Improved HDSS: 33.3% HQLQ= 74
Case 8	Major intervention by mentor (right side; near miss) Persistent intercostal neuralgia (left side) Improved HDSS: 33.3% HQLQ= 77
Case 19	Major intervention by mentor (left side; confusing anatomy) Improved HDSS: 50%
Case 32	Improved HDSS: 25% HQLQ= 55

evaluate the competence of trainees [36–39]. Such technique proved useful in demonstrating the learning curve associating new-skill acquisition in an objective manner and documentation of competence in practice among

trainees. We conducted the CUSUM analysis using sequential probability ratio testing which was found to provide a more sensitive analysis of the performance in progress, when there is rapid enhancement in the skills



level (training situation), compared to cumulative failure charting [40]. The trainee showed a steep curve of evaluation scores indicating rapid acquisition of orientation reaching a plateau at the 10th case that remained steady during the “training phase”.

The CUSUM chart for the operating time showed an initial out-of-control process coinciding with consolidating anatomical orientation, acquiring manipulation skills and getting integrated into the OR team. By the 5th case, gradual improvement was noticed as the trainee acquired more confidence, hand dexterity, and more integration into the OR team. By the 8th case, the process became under control and toward a steady state till the OR shift happened at the 20th case. In the neurosurgical OR, a new team was integrated and the operating time became significantly longer. This deviation continued over 6 procedures, after which the curve regained its downward slope till the state of competency was achieved when the curve flattened at the 24th case. It was noticed that although the experience of both the surgeon and the OR team can impact the operation time; the impact of the surgeon’s experience was more obvious on the CUSUM curve. It took about 7 cases for the practicing surgeon to keep the operating time under control in the presence of an experienced OR team, while control was fulfilled over just 3 cases when the practicing surgeon who got some experience operated with an inexperienced team.

Although it took more time by the trainee before blood loss became under control compared to operating time, the acquired skill of hemostasis was less affected by the OR team replacement than did the operating time. This was revealed by a curve that remained under the upper

CUSUM line indicating an under-control process. Moreover, the trainee reached competency in hemostasis earlier than he did regarding the operating time.

The CUSUM chart of failure showed inconclusive evidence about performance in which no trend was noticed and failures were as expected. This means that the procedure is generally feasible and undemanding for trainees. There was no procedure that turned open during the study. Moreover, no catastrophic complications were encountered resulting in death or major deficits. The success rate in this series reached 92% of cases which is comparable to other studies [41, 42]. However, this may carry some optimism, as long-term outcomes like recurrence were not included. The major interventions by mentors were considered potential failures as major complications were expected in case these procedures were accomplished by the trainee. Improvements of 50% or less in HDSS (8% of cases) and HQLQ scores more than 51 at 3 months (6% of cases) were also considered failures. The two cases of intercostal neuralgia (4% of cases) were managed successfully by the pain control team; however, they were included among failures as they were considered disabling complications requiring repeated intercostal blocks. Although a significant improvement in blood loss was noted after the first 10 cases and a similar improvement in operative time after the first 20 cases, failures and hospital stays showed no significant differences among groups. This indicates that the procedure is generally safe and effective with a steep learning curve and rapid acquisition of skills over time even in young neurosurgeons with no experience in open sympathectomy or extracranial endoscopy.

Conclusion

Mentored surgical training on VATS sympathectomy proved to be a safe and an effective training method with detected failures within expected limits. We found it reasonable to consider an average of 20 cases to be a prerequisite for a neurosurgeon with basal knowledge to attain technical competence in VATS sympathectomy. The experience of the OR team plays an important role in the rapid improvement and consistency of performance. These results should be reproduced by analyzing the performance of more neurosurgical trainees to adjust for personal variations.

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Authors’ contributions

Both authors mentored the trainee although the study. HA analyzed and interpreted the trainee’s performance and was a major contributor in writing the manuscript. YE shared in data analysis and outcome assessment. Both authors read and approved the final manuscript.

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Availability of data and materials

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

Declarations**Ethics approval and consent to participate**

The current study was approved by the local IRB, with written informed consents obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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