

Learning Curve for the Acquisition of 20 Standard Two-Dimensional Images in Advanced Perioperative Transesophageal Echocardiography: A Prospective Observational Study

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Abstract

Background

Learning to perform intraoperative transesophageal echocardiography takes time and practice. We aimed to determine the cumulative success rate in the first 20 intraoperative transesophageal echocardiography cases performed by trainee anesthesiologists with no transesophageal echocardiography experience.

Methods

This prospective observational study included nine anesthesiologists (four cardiovascular and thoracic anesthesia fellows and five short-course perioperative intraoperative transesophageal echocardiography trainees). Overall, 180 studies self-performed by the trainees were reviewed by certified reviewers. A study was considered successful when at least 15 qualified images were collected within 30 minutes. The cumulative success of each trainee was used as a surrogate of a basic two-dimensional intraoperative transesophageal echocardiography learning curve.

Results

The participants comprised three male and six female anesthesiologists aged 29–43 years with 2–13 years of work experience. Most studies (146/180, 81.11%) were completed within 30 minutes, and the cumulative success rate was 70–90% (average $82.78 \pm 6.71\%$). The average cumulative success rate in the short-course group ($85 \pm 7.07\%$) was higher than that in the official cardiovascular and thoracic fellow trainee group ($80 \pm 7.07\%$). The recommended caseload for a 75–80% success rate was 14–18 cases (95% confidence interval, 0.675–0.969).

Conclusions

We recommended a 14–18 caseload for a target success rate of 75–80% in studies performed by trainees with no previous experience. Our findings will enable the development of programs to train anesthesiologists in intraoperative transesophageal echocardiography.

Background

Transesophageal echocardiography (TEE) has evolved into a standard practice during open heart surgery and has become a fundamental skill that all cardiovascular and thoracic anesthesiologists must gain. Generally, TEE can be used as an intraoperative hemodynamic monitoring technique, but more specifically, it can provide significant surgery-related information, such as structural defects that mandate repair and information on the position of the cannulas or devices [1, 2].

Generally, the formal cardiovascular and thoracic fellowship training takes 1–2 years depending on the institution's curriculum. TEE is one of the required skills among several other cardiovascular and thoracic anesthesia-related proficiencies. According to the American Society of Echocardiography/Society of Cardiovascular Anesthesiologists guideline, 20 standard two-dimensional TEE views must be part of a comprehensive examination [3]. Although new recommendations have been published [4], This guideline was used as a reference for beginners long before new technologies such as tissue Doppler and three-dimensional imaging emerged. Learning to acquire standard TEE images is a fundamental skill that should be acquired before a trainee can move on to measurements, interpretation, or more advanced TEE procedures [4].

TEE training requires basic knowledge, i.e., the principles of ultrasound, cardiac anatomy, probe manipulation, and image acquisition. This can be learned in a class or by self-study from standard textbooks. The next step involves hands-on practice. Historically, trainees would perform their first TEE examination on an actual patient (usually under anesthesia). However, currently, many simulation-based systems can facilitate such training [5–13]. To be granted a diploma in advanced perioperative TEE by the American National Board of Echocardiography, a log that includes a minimum of 150 self-performed cases and 150 TEE study reviews and reports under supervision must be submitted, in addition to passing a multiple-choice question examination [14]. To perform and interpret these many TEE studies during training, a determined effort is required. Obtaining 20 standard two-dimensional images is only the beginning of the advanced perioperative TEE training. Learning to accomplish the measurements, perform Doppler TEE, and interpret and report the results are the subsequent steps. Previous studies that reported the number of cases required by trainees have been based in intensive care unit (ICU) settings [15, 16]. With limited data regarding the learning curve for intraoperative TEE, in this study, we aimed to explore the success rate among trainees with no experience in performing intraoperative TEE.

Methods

We determined the number of TEE studies required using a nQuery Advisor. We set a confidence interval at 0.950 and expected final success rate at 80–85%, yielding 196–246 studies, considering the number of cases as approximately 20–25, which are usually handled during the initial training phase in our institution in the past 5 years. As such, we planned to include 10 trainees, each performing 20 studies to a total of 200 studies for the analysis. We invited all trainees (four formal cardiovascular and thoracic fellows and six anesthesiologists) who applied for a 3-month short course on perioperative TEE training between 2014 and 2016 to participate in the study. However, one short-course TEE trainee was excluded due to her prior experience in TEE (she had performed more than 10 examinations), and a total of nine trainees were finally enrolled. All patients in this study were undergoing open heart surgery and required intraoperative TEE. They all received standard general anesthesia with an endotracheal tube. TEE probe insertion and examination began soon after anesthesia before the surgical incision was made.

All trainees received lectures on four basic topics (ultrasound principle, normal cardiac anatomy, probe placement, and image acquisition, and normal variants and artifacts). Due to the shorter training time (3

months) for the short-course trainees, they received a total of 12 hours of hands-on TEE manikin simulation (HeartWorks; Inventive Medical Ltd., London, UK). All trainees also underwent a 1-hour knobology session on the actual ultrasound machine (Philips iE33; Philips Ultrasound, Inc., Bothell, WA, USA). They also received one-on-one demonstrations and self-performed TEE (closely supervised) on two or three actual patients. By adopting a deliberate practice model [17–19], for their next 20 examinations, the trainees performed TEE on their own. They were instructed to digitally acquire 20 standard two-dimensional TEE images within a 30-minute period that started when the first image was recorded and ended when the last image was recorded. The on-site attending anesthesiologist ensured patient safety during the examination without providing any specific guidance for image acquisition. After 30 minutes, the trainees could continue acquiring images, but the images acquired thereafter were not counted. All images were transferred to a server (Philips Xcelera R3.1L1, 3.1.1.422–2009). All 180 TEE studies from the nine trainees were then independently reviewed by a panel of three anesthesiologists who had passed the National Board of Echocardiography or an equivalent perioperative TEE board examination. All reviewers were blinded to the trainees' identity, and images were accepted when each standard two-dimensional TEE image was approved by at least two out of the three reviewers. The images must contain the structure of interests in each specific view with acceptable quality, as listed in our study protocol [see Additional file 1]. The entire study was categorized as successful when at least 15 out of 20 qualified images were collected within 30 minutes based on data obtained from previous trainees.

Statistical analysis

We used a binomial distribution to determine the probability of a successful or failed outcome. For the 95% confidence interval, Wald-Type confidence intervals for p-values were calculated, where “p” was the success rate probability. The success rate for each attempt by each trainee was reported. We used SPSS statistics (version 18, IBM SPSS Statistics) to analyze the multiple linear regression of the 20th case's success rate among every trainee's variables. We constructed the learning curve of each trainee by plotting the success rate on the y-axis versus the number of studies on the x-axis. We also calculated the mean success rate with 95% confidence intervals of all trainees and determined the recommended mean caseload based on a success rate of 75–80% [18]. The mean and standard deviation of the success rate by the 20th TEE attempt and the time spent on each study by each trainee were calculated.

Results

Basic demographic data of all trainees and details regarding their first 20 TEE studies are shown in Table 1. From all 180 studies, the time taken for each study ranged from 9 to 61 minutes with an average of 25.99 minutes. Each trainee underwent image acquisition within the 30-minute timeframe, but every trainee had at least 1–9 case(s) that exceeded 30 minutes. The qualified images shown in Table 1 are those acquired within the permissible 30 minutes with acceptable quality as assessed by the panel of reviewers. There were large variations in success rate patterns among trainees, with some achieving initial success and others meeting considerably less success at the beginning (Figure 1). However, all trainees demonstrated an increasing success rate toward their 20th case. The cumulative success rate by

the 20th case was between 70% and 90% (mean 82.78±6.71%). Five trainees managed to acquire all 20 standard two-dimensional TEE images (absolutely complete) within 30 minutes at least once in their first 20 cases. There were only nine complete studies out of the 180 examinations, representing a rate of 0.05%.

The mean success rate of all trainees is shown in Figure 2. Despite the early success observed in a few trainees, this was offset by some individuals with early failure. The overall pattern was an initial moderate success rate (55.56%), followed by a dip to as low as 44.44% on the second and third case, and then a gradual and steady increase up to 82.78% on the 20th case. All trainees managed to achieve a 100% success rate for their last five cases (cases 16–20).

In terms of the recommended caseload to achieve a success rate of 75–80%, this was calculated as 14–18 cases for each trainee (Figure 3). Based on these values, the 95% confidence interval was 0.696–0.959.

The results of multiple linear regression analysis for the different subgroups of trainees are shown in Table 2. Although the success rates were higher for younger trainees, trainees with a lesser number of years after residency training, male trainees, and trainees taking short courses, the differences were not statistically significant.

Table 2. Comparisons between different subgroups of trainees and the results of multiple linear regression analysis

Subgroup	N	Success rate at 20 th case	β	Standard error (β)	p-value
Age (years)			2.953	4.322	0.532
Sex					
Female	6	82.5 ± 8.2			
Male	3	83.3 ± 5.8	1.287	5.366	0.822
PRY (years)			-2.363	5.056	0.665
Trainee types					
Short course	5	85.0 ± 7.1			
Full year	4	80.0 ± 7.1	-6.727	7.742	0.434

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_p x_{ip} + e$$

where, for $i=n$ observations:

y_i =dependent variable

x_i =explanatory variables

β_0 =y-intercept (constant term)

β_p =slope coefficients for each explanatory variable

ϵ =the model's error term (also known as the residuals)

PRY: post-residency year (number of years after residency training)

Discussion

In this study, we determined the success rate in the first 20 intraoperative TEE procedures performed by trainees with no experience. We reported a cumulative success rate of 70–90%, with most studies completed in less than 30 minutes. The recommended caseload to achieve a 75–80% success rate is 14–18; this only applies to the acquisition of 20 standard two-dimensional images.

Learning to perform TEE has been gradually integrated into fellowship training for cardiovascular and thoracic anesthesia. The acquisition of TEE images is considered more technically difficult than transthoracic echocardiography owing to the complexity of probe manipulation and the limited locations of the probe in certain parts of the body. Traditionally, learning intraoperative TEE takes considerable time, and the number of cases required to achieve an acceptable success rate has never been reported. A previous study by Charron [15] proposed that experience with 31 cases over 6 months was required, and a study by Xiang [16], only available in English as an abstract, reported that experience with 36–48 cases was required. However, both reports involved TEE performed on mechanically ventilated patients in the ICU, which is a different setting from that for intraoperative TEE.

Intraoperative TEE is often performed in anesthetized patients by a cardiovascular and thoracic anesthesiologist. In contrast, preoperative TEE is usually performed on mildly sedated patients by a cardiologist in an echocardiography suite. The main obstacles remain bright operating theater lighting, electrocautery interference, and the challenge of maintaining the balance between performing TEE and managing hemodynamics under anesthesia in patients with cardiac diseases.

It typically takes 1–2 years for a cardiovascular and thoracic fellow to develop proficiency in TEE. The National Board of Echocardiography/Society of Cardiovascular Anesthesiologists requires at least 150 self-performed TEE cases for each seeking a diploma in advanced perioperative TEE certification [14]. Each institution may have different approaches to enable their trainees to achieve this number. However, for a trainee requiring a shorter training time, a simulation-based system, e.g., HeartWorks (Inventive Medical Ltd.), can facilitate learning [5–13]. There are currently multiple TEE simulation systems, including online options, and growing evidence of the benefits of TEE teaching.

The trainees recruited for this study were within a wide range of age (29–43 years) and working experience (2–13 years). The wide variation in success rates in their initial attempts (Fig. 1) is consistent

with real-life experience. In the first few attempts of novice trainees, multiple factors, such as individual predispositions (some patients may be more difficult than others), confidence, and preparation, might have a substantial impact. As more cases are completed, the influence of these factors decreases, and the trainees become more successful. This is presented in Table 1, which shows that all trainees passed their last 10 cases, except for trainee #9 who missed case no. 15. If we omit this single late failure, all trainees were able to succeed in their last five cases.

Most TEE studies were completed within 30 minutes (146/180, 81.11%). In our study, most of the prolonged studies were from a single trainee (trainee #3) who accounted for 25% of the total prolonged studies (9/35). Generally, it would be difficult to perform an intraoperative TEE examination for longer than 30 minutes, alongside providing anesthesia care when working with an efficient surgeon. This can only happen with anesthetized patients and when the TEE examiner does not have any other responsibilities. The time could have been shortened if this trainee had been guided by an expert.

This study had some limitations. First, we could not determine an appropriate method to estimate the number of trainees required for an effective sample size. The classic approach of constructing the learning curves of trainees using a cumulative sum method reported by de Oliveira Filho can be used for basic skills, such as peripheral intravenous cannulation and orotracheal intubation [20–21]. However, TEE requires a complex skillset. With a limited number of trainees per year, we instead opted to use nQuery Advisor to determine the number of studies required. Unfortunately, our number of studies was 10% lower than expected due to exclusion of one trainee. Second, the decision to choose a trainee's first 20 cases may appear methodologically limited. However, this number was chosen based on our site-specific data demonstrating the number of TEE cases that our trainees usually perform during the initial phase of their training (1 month for a short-course group and 3–4 months for a full-year fellow). The pace of TEE training was slower for the formal fellows, and they were required to take care of anesthetized patients while performing TEE. In contrast, the short-course trainees only performed TEE. When the overall progress of the two groups was compared, no notable differences were found. However, as this study was not designed to analyze this difference, it is inappropriate to draw any conclusions from our results. Finally, the last issue relates to the inclusion of fee-based short-course trainees in the study. However, this fee was mainly collected to ensure the institution's procurement of equipment and consumable costs. The attending physicians involved in the study did not get paid for bedside teaching. At the time when the study was conducted, the method used was nearly identical to that of routine training. Additionally, the three panel reviewers were blind to the trainees' identities. There was no undue influence regarding the training since the outcome of this study does not have any effects on the outcomes of the actual training.

Conclusions

We reported a cumulative success rate of 70–90% in the first 20 cases among anesthesiologists with no previous TEE experience, which can mostly be achieved (80.55%) within 30 minutes. The recommended caseload to achieve a 75–80% success rate is 14–18 cases. This only applies to the acquisition of 20 standard two-dimensional images. For comprehensive advanced perioperative TEE training, trainees will

need more self-performed cases, as well as case reviews with experts. Our findings will be useful for the development of future training programs for anesthesiologists learning to perform TEE.

Abbreviations

TEE, Transesophageal echocardiography

ICU, Intensive care unit

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Ethics Committee of Siriraj Hospital, Mahidol University (No.: Si 232/2014). Written informed consent was obtained from all participants.

Consent for publication

Not applicable

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

PS designed the study, reviewed the images, helped with abstract writing and the submission process, and oversaw the entire project. ST helped prepare the research proposal, assisted with image archiving and preparation, drafting the abstract, and additionally served as a research coordinator. VC project consultant cardiologist, helped drafting the proposal and abstract. KR reviewed the images, contributed to writing the abstract, and reviewed the final manuscript. KV reviewed the images. All authors read and approved the final manuscript.

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Tables

Due to technical limitations, table 1 is only available as a download in the Supplemental Files section.

Figures

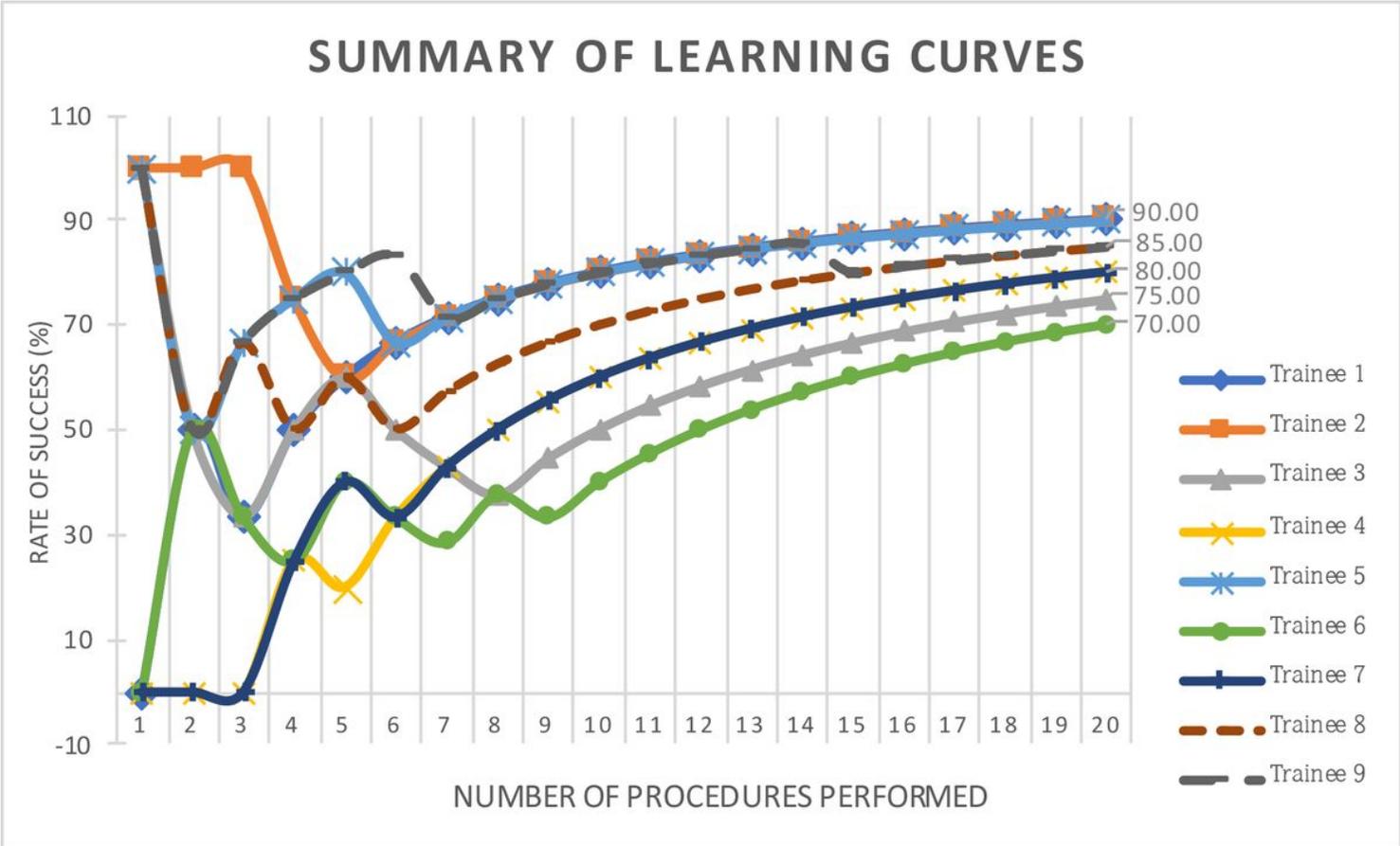


Figure 1

Learning curve of each trainee for performing their first 20 transesophageal echocardiography (TEE) examinations. The cumulative success rate ranges from 70% to 90% by the 20th case

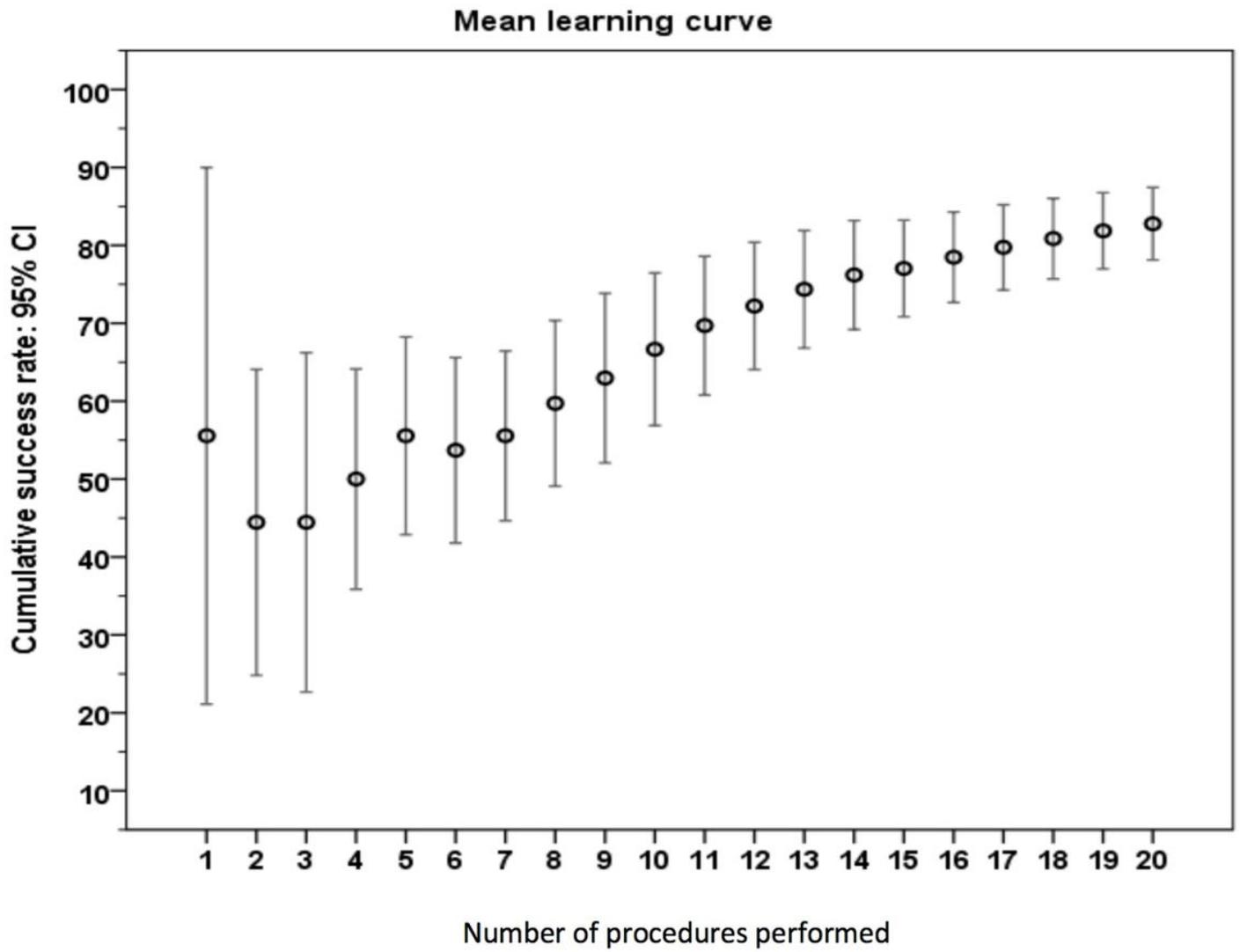


Figure 2

The mean learning curve of all trainees

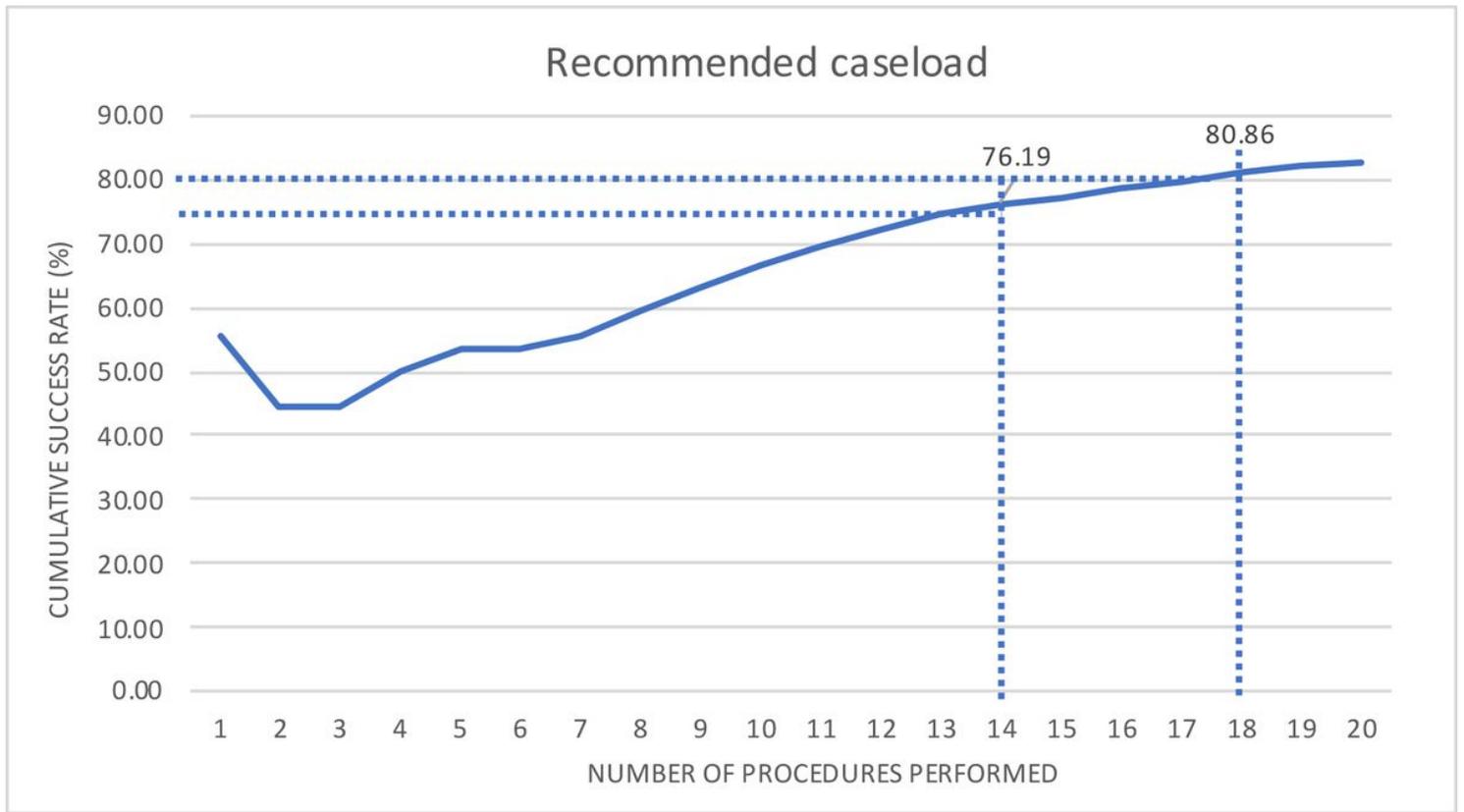


Figure 3

Extrapolation plot of the recommended caseload when aiming for a 75%–80% success rate

Supplementary Files

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