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Original Article

Learning Curve of Autologous Arteriovenous Fistula Formation for Junior Vascular Surgeons

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Purpose: Autologous arteriovenous fistulas (AVFs) are considered the gold standard for hemodialysis access, with outcomes largely dependent on the surgeon's experience. Nevertheless, few studies have been conducted on the learning curve of junior vascular surgeons in AVF creation. This study aims to address this by examining the development of surgical skills among junior vascular surgeons.

Materials and Methods: A retrospective analysis was conducted on 100 patients who underwent autologous AVF procedures performed by five junior surgeons between January 2018 and December 2023. To establish the cutoff number of cases for the learning curve, we examined the cubic spline curve using the hazard ratio for primary failure.

Results: The cutoff number for operation cases was 15.33, and we divided the analysis into a pre-learning curve period (≤15 cases of AVF) and a post-learning curve period (>15 cases of AVF). The 1-year primary patency rate for AVF during the post-learning curve period was 84.0%, which was higher than the 65.5% rate observed during the pre-learning curve period. In a subgroup analysis based on AVF type, the radiocephalic fistula patient group demonstrated a significant increase in 1-year primary patency in the post-learning curve period compared to that in the pre-learning curve period (80.0% vs. 43.0%, log-rank P=0.033). In contrast, there was no significant difference in the primary patency rates between the post- and pre-learning curve periods in the brachiocephalic fistula patient group (90.0% vs. 89.2%, log-rank P=0.930).

Conclusion: Junior vascular surgeons demonstrated improved primary AVF patency beyond the learning curve benchmark in 15 patients, with particularly notable enhancements in radiocephalic fistulas.

Key Words: Arteriovenous fistula, Learning curve, Vascular patency

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INTRODUCTION

An autologous arteriovenous fistula (AVF) is the preferred vascular access for patients requiring hemodialysis because of its longer patency and lower complication rates compared to other types of vascular access, such as arteriovenous grafts (AVGs) [1-4]. The creation and maintenance of a functional AVF is complex and can be influenced by several factors, including the surgeon's skill. Known risk factors that affect AVF patency include patient-related factors such as age and sex, comorbidities such as diabetes or hypertension, previous vascular access history, and vessel-related factors such as arterial quality and vein diameter [5-7].

While it is recognized that the technical expertise required for AVF creation is a significant barrier to its success, there is a lack of data regarding how a surgeon's expertise influences AVF outcomes. The 'learning curve' concept represents a period during which a surgeon gains experience and proficiency in a procedure, leading to improved outcomes. Understanding the learning curve for autologous AVF is important not only for junior surgeons who are starting vascular surgery, but also for senior surgeons who educate younger surgeons.

Therefore, this study analyzed the outcomes of AVFs created by junior surgeons at varying stages of their fellowship training to provide insights into the effects of experience on AVF patency rates.

MATERIALS AND METHODS

A retrospective analysis was conducted on 100 consecutive patients who underwent autologous AVF procedures performed by five junior surgeons between January 2018 and December 2023. 'Junior surgeon' referred to a fellow undergoing vascular surgery fellowship training at our hospital. Among these surgeons, four (A, C, D, and E) performed AVFs during their first or second year of fellowship training in the Transplant and Vascular Surgery Department following their general surgery residency. The fifth surgeon (B) completed a 2-year fellowship in Hepato-biliary-pancreas (HBP) surgery and accrued 2 years of clinical experience as an HBP surgeon before undertaking AVF procedures in their first year of fellowship training within the same department.

Two types of autologous AVF were performed: radiocephalic fistula (RCF) and brachiocephalic fistula (BCF). Preoperative evaluation and vascular mapping were performed using Doppler ultrasonography at the outpatient clinic. A senior vascular surgeon determined the surgical plan for all cases. All AVF procedures performed by the five junior surgeons were conducted independently without intervention from the senior surgeon, but in an environment where a senior surgeon who could supervise was present if there were any issues.

All study procedures were conducted in accordance with the Declaration of Helsinki and were approved by the Institutional Review Board (IRB) of Severance Hospital (IRB No. 4-2023-1580). The need for informed consent was waived owing to the retrospective study design.

1) Definitions

Primary patency, also known as intervention-free access survival, was defined as the period from the time of access placement to the occurrence of any intervention designed to maintain or reestablish patency, the presence of access thrombosis, or the time of patency assessment [8].

Primary failure was characterized as an AVF that either failed to mature adequately for dialysis or was thrombosed before the first successful cannulation for hemodialysis, irrespective of subsequent AVF abandonment. This definition encompasses inadequate maturation, early thrombosis, failed first cannulation, and other complications, such as ischemia or infection [9].

2) Statistical analysis

To determine the learning curve for autologous AVF formation by junior surgeons, we performed a cubic spline curve on the primary failure hazard ratio (HR) to set a cut-off number of operations where the HR was <1. Additionally, we conducted a cumulative sum (CUSUM) analysis based on the operation times of the AVFs consecutively performed by the five junior surgeons.

Data were presented as frequencies, means±standard deviation, or median and interquartile range (IQR), depending on the nature of the data. Categorical variables were compared using the χ^2 and Fisher exact tests, while continuous variables were analyzed using the Student t-test or Mann–Whitney U-test depending on the distribution of the data.

In the entire cohort, the primary patency rates according to AVF type and their corresponding positions on the learning curve (either the pre- or post-learning curve period) were assessed using the Kaplan–Meier curve and log-rank test. A subgroup analysis based on AVF type was conducted to investigate the specific impact of the learning curve period on primary patency rates using the Kaplan–Meier curve.

RESULTS

1) Baseline characteristics

In this study, 100 cases of autologous AVFs were analyzed, with an equal distribution between AVF types, each comprising 50 cases (50.0%). Each junior surgeon performed autologous AVFs in the following number of cases: Surgeon A performed autologous AVFs in 27 cases, Surgeon B in 22 cases, Surgeon C in 20 cases, Surgeon D in 16 cases, and Surgeon E in 15 cases.

The patient demographic was predominantly male, representing 69 individuals (69.0%), with a median age of 66.0 years (IQR: 55.0-75.0). The median operation time was 71.0 minutes (IQR: 63.5-80.5). Hypertension, diabetes, coronary artery disease, and cerebral vascular disease were observed in 78.0%, 47.0%, 16.0%, and 5.0% of the cases, respectively (Table 1).

2) Determining the learning curve of AVF

To set the cutoff number of cases for the learning curve, we examined the cubic spline curve using the HR for primary failure. The cut-off number of operation cases at which the HR became less than 1 on the cubic spline curve, was 15.33 (Fig. 1). Therefore, in this study, we divided the analysis into the pre-learning curve period (≤15 cases of AVF) and the post-learning curve period (>15 cases of AVF) based on the aforementioned cut-off value.

When comparing the baseline characteristics of the pre- (n=75) and post-learning curve periods (n=25), no statistically significant differences were observed in sex, age, AVF type, underlying disease, radial/brachial artery size, and cephalic vein size. However, there was a trend towards a shorter total operation time in the post-learning curve period, with an operating time of 66.0 minutes (IQR: 58.0-82.0) compared to 72.0 minutes (IQR: 66.0-80.0) in the pre-learning curve period (P=0.076) (Table 1).

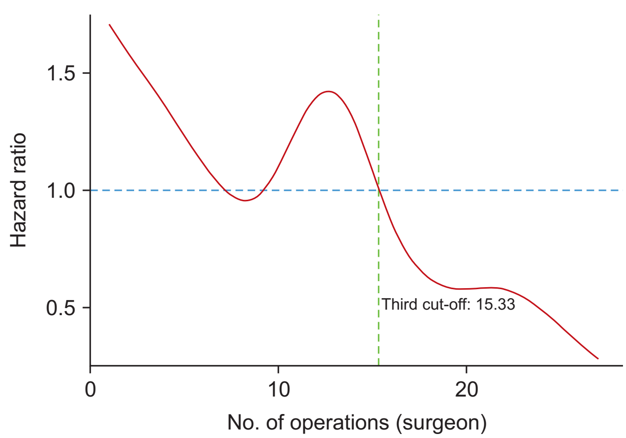

Fig. 1. Cubic spline curve for the hazard ratio of primary failure in autologous AVFs. AVF, autologous arteriovenous fistulas.

3) Comparison of primary patency according to learning curve

Irrespective of the AVF type, the 1-year primary patency rate during the post-learning curve period was 84.0%. This rate was higher than that in the pre-learning curve period, which had a 1-year primary patency rate of 65.5%; however, this difference was not statistically significant (log-rank P=0.110) (Fig. 2).

4) Comparison of primary patency according to AVF type

In the entire cohort, when comparing primary patency rates according to AVF type, the 1-year primary patency rate for BCF was significantly higher at 89.4% compared to 54.8% for RCF (log-rank P<0.001) (Fig. 3). There were 22 primary failure cases in the RCF group, with 17 patients

Table 1. Baseline characteristics

Variable	Entire cohort (n=100)	Pre-learning curve period (n=75)	Post-learning curve period (n=25)	P-value
Sex, male	69 (69.0)	51 (68.0)	18 (72.0)	0.901
Age (y)	66.0 (55.0-75.0)	65.0 (55.0-74.5)	66.0 (55.0-75.0)	0.820
Operation time	71.0 (63.5-80.5)	72.0 (66.0-80.0)	66.0 (58.0-82.0)	0.076
AVF type, BCF	50 (50.0)	40 (53.3)	10 (40.0)	0.356
Underlying disease				
HTN	78 (78.0)	58 (77.3)	20 (80.0)	>0.999
DM	47 (47.0)	36 (48.0)	11 (44.0)	0.908
CAD	16 (16.0)	10 (13.3)	6 (24.0)	0.345
CVD	5 (5.0)	4 (5.3)	1 (4.0)	>0.999
Preoperative ultrasound evaluation				
Cephalic vein size	3.1 (2.6-3.8)	3.1 (2.7-3.8)	3.2 (2.6-3.8)	0.869
Radial/brachial artery size	3.2 (2.5-4.0)	3.3 (2.6-4.2)	2.8 (2.3-3.8)	0.144

AVF, arteriovenous fistula; BCF, brachiocephalic fistula; CAD, coronary artery disease; CVD, cerebrovascular disease; DM, diabetes mellitus; HTN, hypertension.

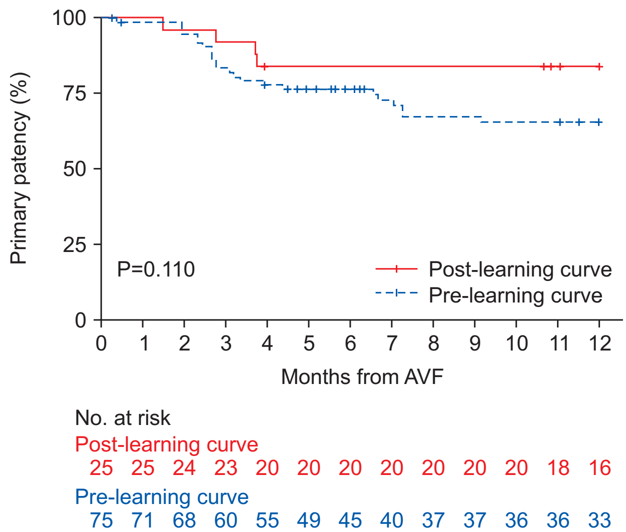

Fig. 2. Kaplan–Meier curve showed primary patency of autologous AVFs according to the learning curve. AVF, autologous arteriovenous fistulas.

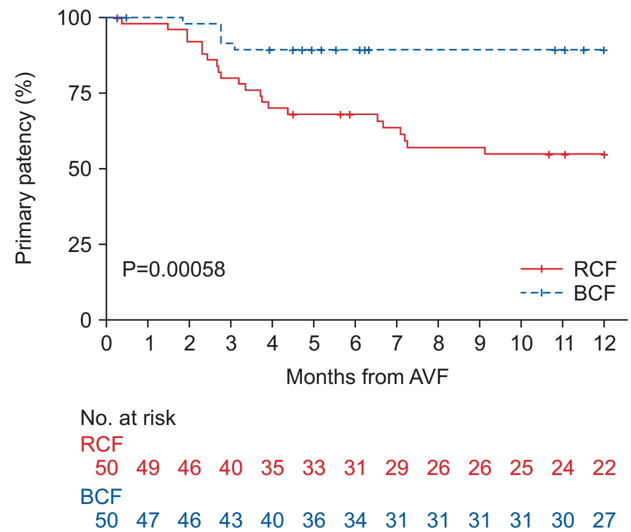

Fig. 3. Kaplan–Meier curve of primary patency in autologous AVFs, categorized by AVF type. AVF, autologous arteriovenous fistulas; RCF, radial-cephalic fistula; BCF, brachio-cephalic fistula.

(77.3%) undergoing percutaneous transluminal angioplasty (PTA) intervention and five patients (22.7%) undergoing surgical intervention (reoperation). Of the five patients who underwent surgical intervention, in four cases, RCFs were abandoned, and a new AVF or AVG was created; three patients underwent BCF due to severe juxta-anastomosis stenosis, maturation failure, and obstruction of the RCF, respectively; while in one case, a brachio-basilic AVG was performed due to an obstructed RCF. In the remaining patients, the existing RCF was preserved, and only juxta-anastomosis branch ligation was performed for maturation.

In contrast, there were five primary failure cases among the BCFs, all of which underwent PTA intervention. The PTA sites consisted of three cases of juxta-anastomosis, one case of a draining vein, and one case of both juxta-anastomosis and draining veins.

5) Subgroup analysis according to AVF type

In a subgroup analysis based on AVF type, the RCF patient group demonstrated a significant increase in 1-year primary patency in the post-learning curve period compared to that in the pre-learning curve period (80.0% vs. 43.0%, log-rank P=0.033) (Fig. 4A).

Among the 19 cases of primary failure within 1-year after surgery that occurred during the pre-learning curve period, PTA intervention was performed in 15 patients (78.9%), and surgical intervention was performed in four patients (21.1%). Regarding the PTA site, 13 cases (86.7%) involved the juxta-anastomosis and the draining vein was involved in two cases (13.3%). Of the four cases of surgical intervention, two were due to obstruction, one was due to maturation failure, and one was due to juxta-anastomosis stenosis, leading to the abandonment of the RCF and the creation of three new BCFs and one brachio-basilic AVG. Among the three cases of primary failure within 1-year after surgery that occurred during the post-learning curve period, PTA intervention was performed in two patients (66.7%) at the juxta-anastomosis, and surgical intervention (juxta-anastomosis branch ligation) was performed in one patient.

In contrast, there was no significant difference in the 1-year primary patency rates between the pre- and post-learning curve periods in the BCF group (90.0% vs. 89.2%, log-rank P=0.930) (Fig. 4B).

6) CUSUM analysis of operation time

Additionally, to understand the learning curve for AVF from a different perspective, a CUSUM analysis was conducted using the total operation time in the order in which each surgeon performed the 100 procedures. According to the CUSUM analysis, the mastery period was entered as the total operative time decreased in 20 cases (Fig. 5A). According to the CUSUM analysis of each surgeon who performed >20 cases of AVF, Junior Surgeons A and C typically showed a steep increase in the operation time during the initial learning period. This was followed by a plateau in the competent and mastery periods, in which the operation time decreased after 20 and 11 cases, respectively. Surgeon B exhibited a more variable CUSUM, with both increases and decreases, indicating an inconsistent operation time (Fig. 5B).

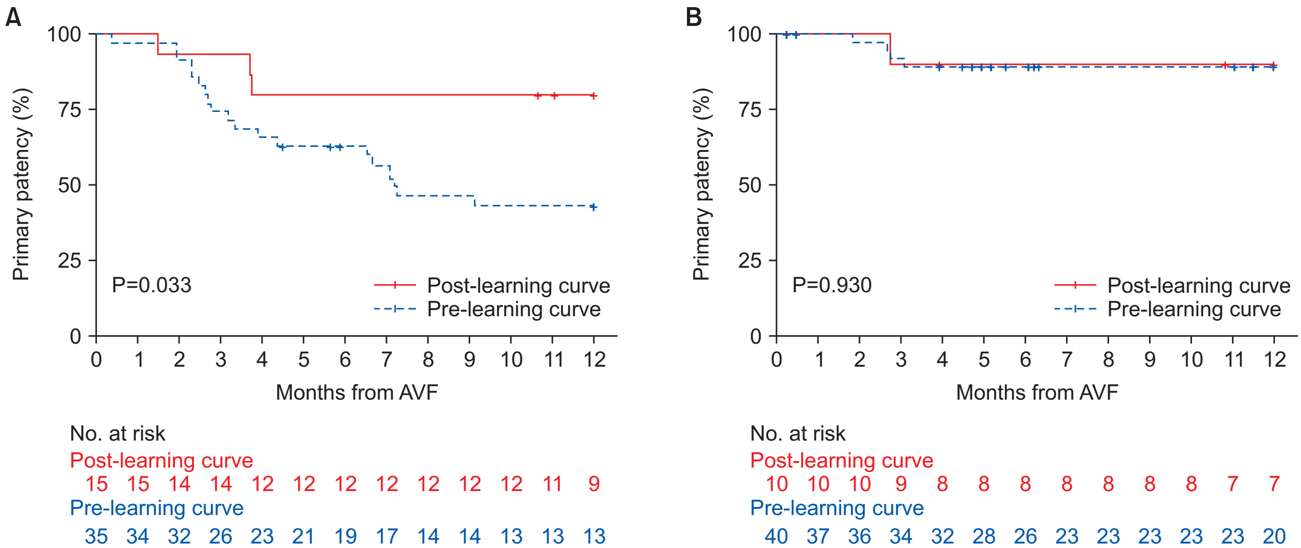

Fig. 4. Kaplan–Meier curve of primary patency in autologous AVFs within subgroups defined by AVF type, according to the learning curve: (A) RCF patient subgroup, (B) BCF patient subgroup. AVF, autologous arteriovenous fistulas; RCF, radial-cephalic fistula; BCF, brachio-cephalic fistula.

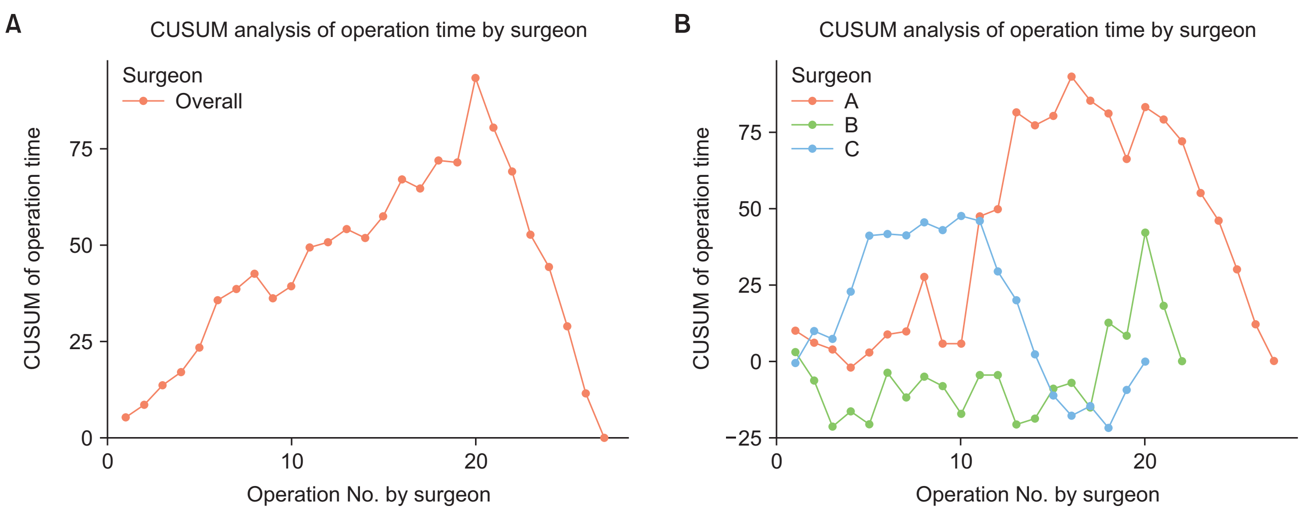

Fig. 5. Cumulative sum analysis of operation times in autologous AVF: (A) CUSUM analysis for all junior vascular surgeons. (B) CUSUM analysis for each surgeon who performed more than 20 cases of AVF (Surgeons A, B, and C). AVF, autologous arteriovenous fistulas. AVF, autologous arteriovenous fistulas; CUSUM, cumulative sum; RCF, radial-cephalic fistula; BCF, brachio-cephalic fistula.

DISCUSSION

The learning curve for junior surgeons performing autologous AVFs is a crucial factor in the success of the procedures. This study applied the cubic spline curve to the primary failure HR, suggesting a cutoff value of 15 cases for the learning curve of autologous AVF performed by junior vascular surgeons. Although the difference in the 1-year primary patency rates between the pre- and post-learning curves was not statistically significant, there was a noticeable trend towards improvement. In particular, in the subgroup analysis, the RCF patient group demonstrated a significant increase in 1-year primary patency in the post-learning curve period, emphasizing the importance of the learning curve for RCF.

Although the use of AVFs for vascular access in hemodialysis has progressed over the years, research focusing on the learning curve of novice junior vascular surgeons and the outcomes associated with autologous AVFs is scarce. [10-12]. Saran et al. reported that the probability of primary fistula failure was significantly lower for vascular access surgeons who placed ≥25 fistulas during training [10]. Their study suggests that a minimum of 25 procedures for autologous fistula creation should be recommended for surgical training programs to improve fistula placement rates and patency. However, their study merely stratified surgeons by tertiles of operation numbers and assessed the relative risk using a Cox-regression model without establishing a precise cutoff. Our study corroborates these findings but goes further by applying a cubic spline curve to the primary failure HR, thereby identifying a definitive cutoff value for the learning curve in autologous AVF creation, which is a significant strength of our study.

The post-learning curve period showed a distinct enhancement in the 1-year primary patency for patients with RCF in contrast to the BCF group, as evidenced by this study. This difference is likely due to the specific surgical skills required for smaller arterial and venous diameters in RCF procedures. Moreover, RCFs have a higher risk of non-maturation, tend to require more interventions, and usually have lower cumulative patency rates than BCFs [13-15].

Therefore, there is a need to focus on the learning curve for AVF, specifically the anastomosis location on the forearm or upper arm. Regus et al. [16] observed a significantly higher rate of immediate failure and a lower cumulative primary patency rate for RCF among resident trainee groups, a trend not observed for BCF. They suggested that trainees should gain experience with upper-arm AVF surgeries before attempting forearm AVFs. Similarly, Fassiadis et al. [17] noted lower primary and secondary patency rates for RCFs performed by junior surgeons than those performed by consultant surgeons, advocating that the most experienced team members handle RCF placements. Our study supports these findings, emphasizing the significance of understanding the learning curve for autologous AVF based on the location of the anastomosis. This is crucial not only for novice surgeons entering vascular surgery but also for experienced surgeons responsible for training the next generation.

Meanwhile, the CUSUM analysis of the total operative time in this study displayed varying trends among the junior surgeons. Of the three surgeons (A, B, and C) who moved to the post-learning curve period, Surgeon B exhibited an atypical learning curve, unlike Surgeons A and C. This could be attributed to Surgeon B's extensive experience as an HBP surgeon prior to fellowship training in the Transplant and Vascular Surgery Departments. Interestingly, since no studies have conducted a CUSUM analysis on operation time to elucidate the AVF learning curve, this finding is significant as it suggests that the learning curve for operation time may vary among surgeons. This indicates the need for further research utilizing operative time data from junior surgeons who have performed a greater number of AVF cases.

This study had some limitations. First, the surgical plan was determined by a senior surgeon, which could be seen as both a limitation and a strength. This allowed for a focused analysis of the learning curve in relation to the junior surgeons' technical skills and surgical factors. Second, the learning curve was analyzed based on a relatively small number of cases over a short period for each surgeon, which may not fully represent the breadth of their learning experiences. Finally, this study did not provide long-term outcomes after AVF surgery because of the short follow-up period.

CONCLUSION

Junior vascular surgeons demonstrated improved primary patency of autologous AVFs, particularly for RCFs, after achieving a learning curve threshold of 15 cases. Gaining insight into this learning process is essential for new vascular surgeons starting their careers and for experienced surgeons mentoring the next generation of vascular specialists.

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CONFLICTS OF INTEREST

The authors has nothing to disclose.

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AUTHOR CONTRIBUTIONS

Concept and design: MCC, SJK. Analysis and interpretation: MCC, DGK, SHH, SJK. Data collection: MCC, SHY, SWS, SJY, DGK. Writing the article: MCC, SJK. Critical revision of the article: SHY, SWS, SJY, DGK, SHH. Final approval of the article: SJK. Statistical analysis: MCC, DGK. Obtained funding: none. Overall responsibility: MCC, SJK.

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