The Identification of Factors That Influence the Quality of Bypass Anastomosis and an Evaluation of the Usefulness of an Experimental Practical Scale in This Regard

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■ BACKGROUND: **Several factors associated with interrupted and continuous suturing techniques affect the quality of bypass anastomosis. It is difficult to determine the impact of these factors during surgery. The primary objective of this study was to evaluate factors with the potential to influence the quality of bypass anastomosis using either interrupted or continuous suturing. A secondary objective was to evaluate the usefulness of a practical scale when comparing interrupted and continuous suturing techniques to improve bypass anastomosis.**

■ METHODS: **Interrupted (n = 100) and continuous (n = 100) suturing techniques were used in 200 end-to-side bypasses to a depth of 3 cm and were assessed by 5 neurosurgeons.**

■ RESULTS: **Vessel closing time (P < 0.001), stitch distribution (P < 0.001), intima-intima attachment (P < 0.001), and size of the orifice (P < 0.001) had a significant impact on the quality of the bypass regardless of the suturing technique used. The suturing technique used (interrupted or continuous) and positioning of the recipient vessel (vertical or horizontal) did not significantly influence the quality of anastomosis. Using multivariate analysis, the highest statistical significance with regard to bypass quality was attributed to the large size of the orifice and intimal attachment.**

■ CONCLUSIONS: **There were advantages and disadvantages to both suturing techniques. The scale was a practical way to measure and improve performance.**

INTRODUCTION

Vital steps need to be taken to ensure the quality of vascular anastomosis during bypass surgery.[1-11] It is critical to ensure that the time taken to minimize blood flow during the procedure is as brief as possible, as this is a significant source of stress for the neurosurgeon[12,13] and can impact the quality of suturing. Several factors, including stitch-related leakage, orifice and lumen stenosis, and contact between the naked thread and blood (with the potential for the development of stasis and thrombosis) can impact short-term and long-term functioning of the bypass.

There is support for interrupted and continuous suturing, as both have advantages and disadvantages.[14-17] The use of continuous suturing could reduce the duration of the procedure. It is likely that the extent of blood leakage is less with continuous than with interrupted suturing owing to the exertion of compression circumferentially. However, maintaining symmetric distribution of the sutures is challenging because the thread is stretched. There is also the potential for the development of stenosis of the orifice and lumen using this approach. The compromise between increased stretching (which causes stenosis) and reduced stretching (which causes loose anastomosis and leakage) adds uncertainty to the procedure. Ensuring intimal attachment and preventing exposure of the thread or suture material inside the lumen and direct contact with the blood should be performed to prevent future stasis and thrombosis. The inability to do this is a disadvantage of continuous suturing. To bury the thread inside the wall, it is necessary to stretch it, but this places the anastomotic orifice at risk of stenosis.

An advantage of interrupted suturing in anastomosis is that it has a higher possibility to achieve intimal attachment by applying inverted technique of the anastomosis edges and to prevent the exposure of the thread to blood inside the lumen. Most surgeons

Key words
- Anastomosis
- Bypass
- Practical scale

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require extra time to complete this procedure. Ensuring the equitable distribution of stitches can help to improve the quality of anastomosis by facilitating a wider orifice and lack of contact between the thread and bloodstream.

Technically, the quality of anastomosis during live surgery cannot be directly evaluated and is usually assessed by use of indocyanine green, microvascular Doppler, or intraoperative angiography. However, this assessment does not guarantee the physical and technical quality of the bypass in the long-term. Furthermore, bypass surgery is highly specialized, is not performed in everyday practice, and cannot feasibly be taught in the operating room. Therefore, mandatory validation of the quality of anastomosis using laboratory and experimental testing is required. End-to-side anastomosis, a microsurgical technique, is the most common bypass procedure is performed by neurosurgeons. Thus, the primary study objective was to identify factors that influence the quality of bypass anastomosis. A secondary objective was to evaluate the usefulness of a practical scale in comparing interrupted and continuous suturing techniques with the aim of improving bypass anastomosis.

Video

Video available at www.sciencedirect.com

MATERIALS AND METHODS

For the aim of this study, only end-to-side anastomosis was performed, and the most common superficial temporal artery-to-medial cerebral artery bypass was simulated. A total of 200 anastomosis procedures were carried out to a depth of 3 cm using interrupted ($n = 100$) and continuous ($n = 100$) suturing. For the procedures, 1-mm-wide vessels derived from chicken wings ($n = 100$) and 1-mm-wide wet tubes ($n = 100$) were used. To simulate genuine surgical circumstances, the recipients were positioned vertically in half of cases and horizontally in the other half of cases. The 8 subgroups were:

- Chicken vessel–derived bypass using interrupted suturing and vertical positioning ($n = 25$)
- Chicken vessel–derived bypass using interrupted suturing and horizontal positioning ($n = 25$)
- Chicken vessel–derived bypass using continuous suturing and vertical poisoning ($n = 25$)
- Chicken vessel–derived bypass using continuous suturing and horizontal positioning ($n = 25$)
- Wet tube–based bypass using interrupted suturing and vertical positioning ($n = 25$)
- Wet tube–based bypass using interrupted suturing and horizontal positioning ($n = 25$)
- Wet tube–based bypass using continuous suturing and vertical poisoning ($n = 25$)
- Wet tube–based bypass using continuous suturing and horizontal positioning ($n = 25$)

There were 20 stitches per anastomosis. The interrupted and continuous sutures were made with a 10–0 microvascular suture needle (Muranaka Medical Instruments Co. Ltd., Tokyo, Japan), using a thread cut to a length of 5–6 cm at the start of each bypass procedure. The suturing was performed in the same order: 2 hanging sutures on the axial ends of the bypasses followed by the application of 2 additional hanging sutures to the middle of both sides to form a diamond shape (Figure 1 and Video 1). Two SuperBypass (SB-1607) forceps (TAKAYAMA INSTRUMENTS INC. MURANAKA, Tokyo, Japan), a pair of scissors (MUTOH America Ltd, Natick, MA, USA), a YASARGIL Aneurysm Clip System (Aesculap, Inc., Center Valley, Pennsylvania, USA), and 2 temporary clips comprised the main surgical instruments used. A Webcam C930e (Logitech, Lausanne, Switzerland) was connected to the microscope and a MacBook Pro (Apple Inc., Cupertino, California, USA). Video 1 (720p video quality) was captured using QuickTime (Apple Inc.). Suturing times were determined from the video playback. Five neurosurgeons from institutions outside of Finland each analyzed 200 slides, in which 2 of the best screen shots taken at the end of the bypass were included after the anastomosis procedure had been performed and which highlighted the stitches placed outside and inside the lumen.

Initially, the practical scale was applied to assess the time taken to complete the anastomosis using continuous and interrupted

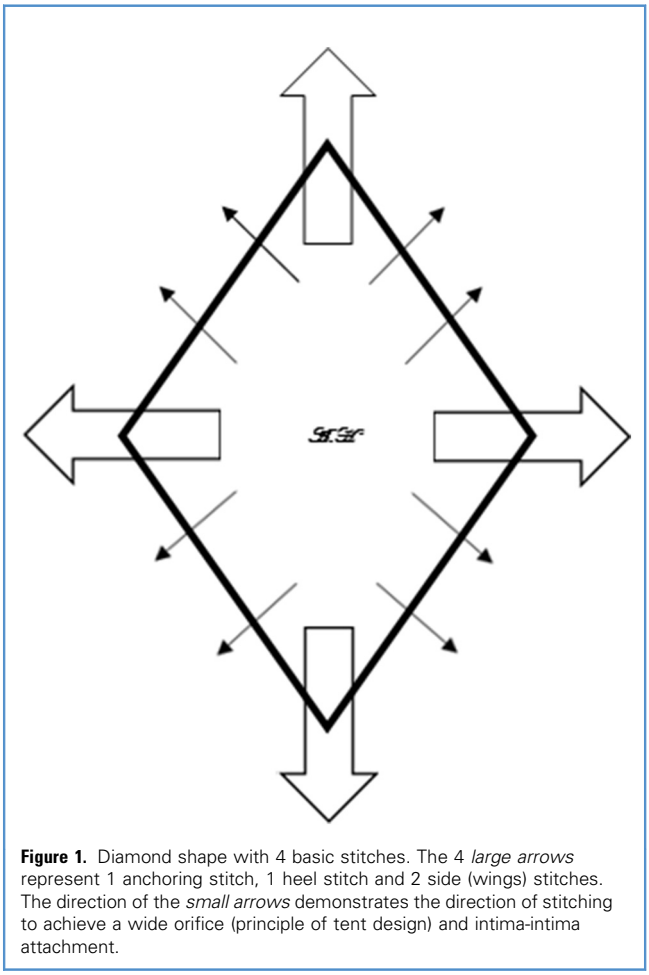

Figure 1. Diamond shape with 4 basic stitches. The 4 *large arrows* represent 1 anchoring stitch, 1 heel stitch and 2 side (wings) stitches. The direction of the *small arrows* demonstrates the direction of stitching to achieve a wide orifice (principle of tent design) and intima-intima attachment.

suturing, determined using the same approach as that used during real surgery (i.e., using temporary clips) (Figures 2 and 3). The time taken for both techniques was determined from the recorded video (that was not edited). A score of 0 was given if the time taken to complete the surgery took ≥20 minutes, and a score of 1 was given if it took ≤20 minutes.

The distribution of stitches on the wall of the vessel was the second factor assessed. A score of 1 was given for favorable and symmetric distribution of stitches, and a score of 0 was given for unfavorable distribution (Figure 4A and B). Next, the impact of intimal attachment on the quality of anastomosis was evaluated, judged according to whether or not the thread could be seen inside the lumen. A score of 1 was awarded if it could not be seen, and a score of 0 was given if it could (Figure 5A and B). Next, the size of the orifice was considered. A score of 1 was awarded if the orifice was equal to or wider than the diameter of the recipient vessel, and a score of 0 was given if it was not (Figure 6A and B).

The suturing technique (i.e., interrupted or continuous) used was also investigated as a key factor with the potential to influence the quality of anastomosis, together with positioning of the recipient vessel (vertical or horizontal) and the type of material used (i.e., a wet tube or chicken wing vessel). However, as the same distribution of materials were used in both groups, a decision was made to exclude the type of material used, as its impact was obvious owing to the difference in texture.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Version 24 (IBM Corp., Armonk, New York, USA). Pearson χ^2 test and binary logistic regression were used to predict the relationship between variables and the proposed scale. A P value of < 0.050 was considered to be statistically significant. The Wald stepwise backward elimination procedures in logistic regression were used with selection variables based on the magnitude of their probability values ($P < 0.1$). By comparing the area under the receiver operating characteristic curves for the factors in relation to the practical scale results, we evaluated the power of prediction for all variables. For the area under the receiver operating characteristic curve, 0.5 is considered indifferent, whereas 1 indicates full discrimination.

RESULTS

Of the 1500 cases, the evaluated factors in the 200 samples were stratified using a scale (Table 1) so that a comparison could be made of the quality of the bypasses achieved using the 2 techniques. Detailed information about the 200 bypass procedures is presented in Table 2.

As an experimental constructive procedure done by suturing, direct evaluation of perfection by cutting the donor close to the orifice and examining the quality based on observation helped us in introducing the relevant elements of what we considered a

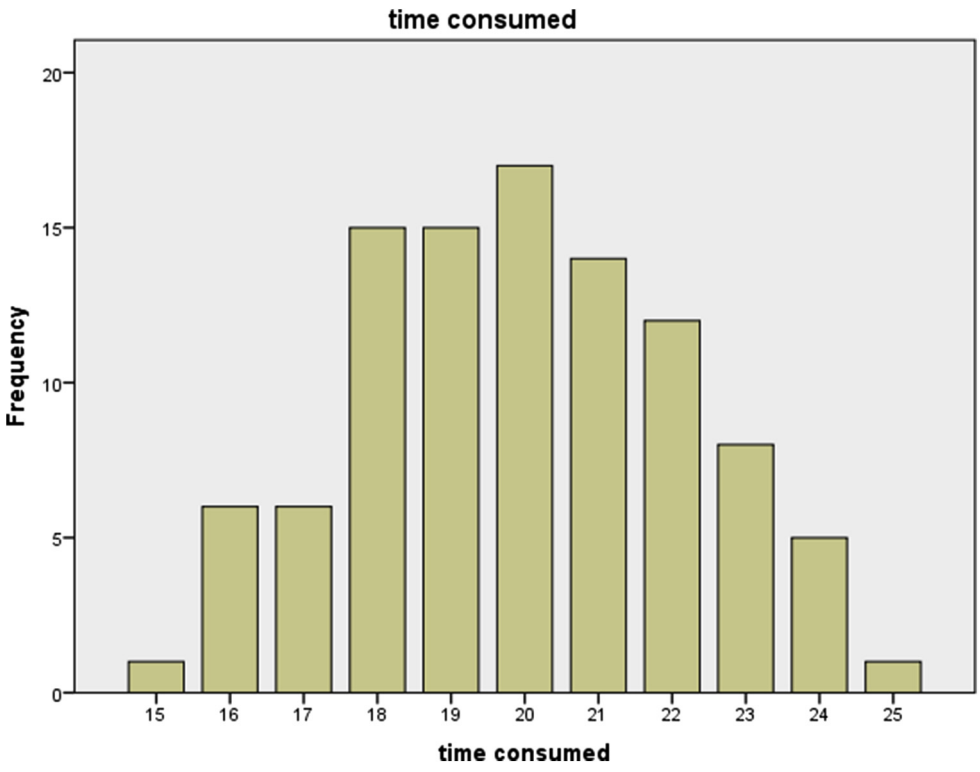

Figure 2. Frequencies of the time taken to complete the anastomosis (time consumed) in interrupted suturing technique in 100 bypasses.

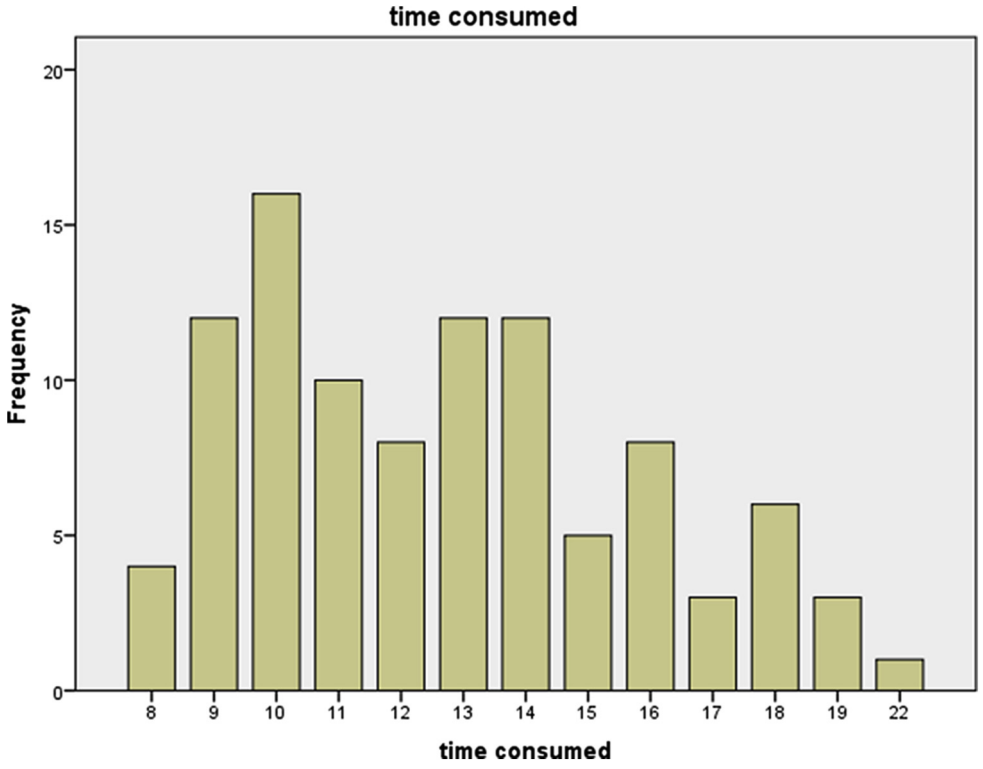

Figure 3. Frequencies of the time taken to complete the anastomosis (time consumed) in continuous suturing technique in 100 bypasses.

successful or failed bypass. Studying a considerable number of our experimental bypasses supported the observation. We analyzed 100 cases in terms of better construction of anastomosis. The multivariable logistic model was constructed to test the association of combined predictor variables with the better construction. A simple practical scale was developed from the data that

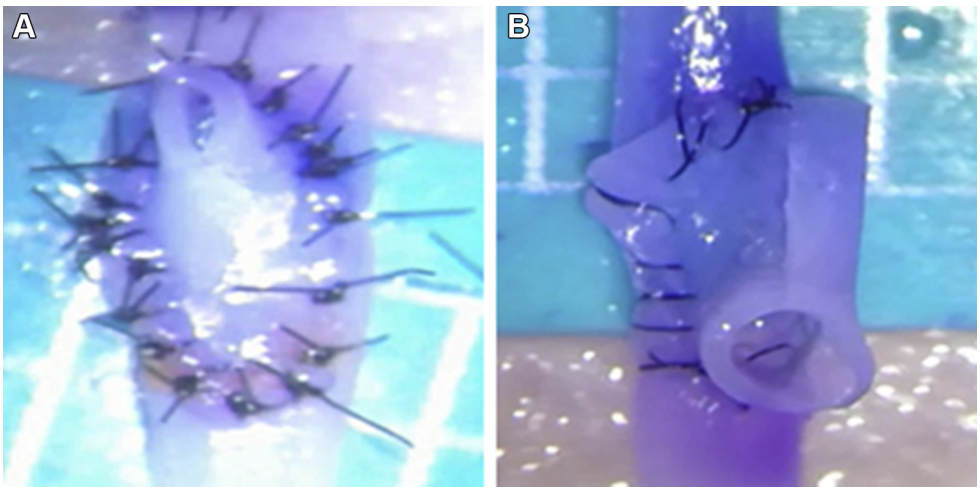

Figure 4. (**A**) Good distribution of stitches. (**B**) Bad distribution of stitches.

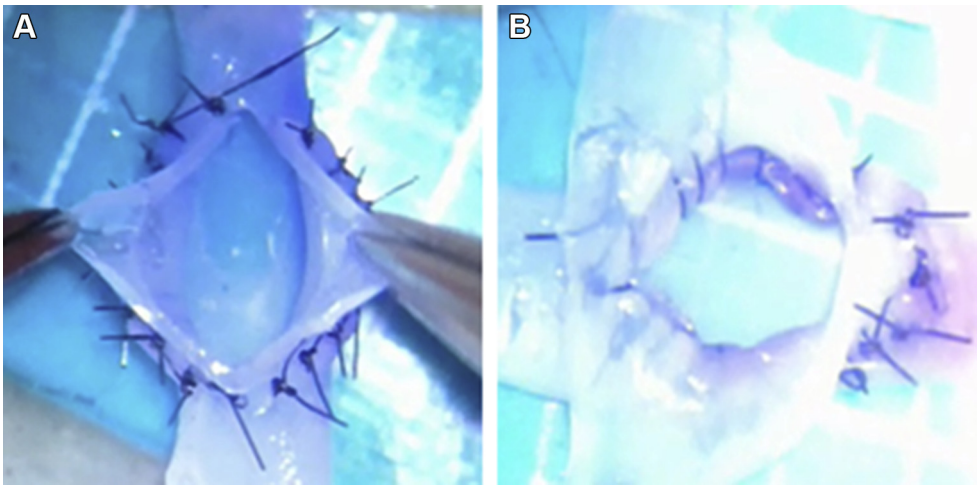

Figure 5. (**A**) No thread can be seen inside the lumen (perfect intima-intima attachment). (**B**) Thread is seen inside the lumen.

combined vessel closure time, distribution of the stitches, size of the orifice, and intima-intima attachment. We constructed a practical scale that included only statistically significant variables. Points were assigned for time taken to close the vessels, size of the orifice compared by the size of the recipient, symmetric distribution of the stitches, and intima-intima attachment as judged by not seeing the thread inside the lumen. The grade ranged from 1 to 4. A good bypass had a higher grade (3 and 4). A grade of 1 or 2 was considered unfavorable (Tables 1 and 2). A significant difference between the use of interrupted or continuous suturing was not demonstrated in the current study with respect to the impact of either on the quality of anastomosis.

The relationship between the individual factors and the suturing technique used is depicted in Table 3. For favorable bypass outcome, significant factors were intima-intima attachment ($P < 0.001$; odds ratio = 31.8) and large orifice size ($P < 0.001$; odds ratio = 55.30) (Table 4).

DISCUSSION

The quality of the stitching is an important factor to evaluate when seeking to determine the quality of anastomosis. It is important to perform laboratory testing, as the surgical expertise of neurosurgeons derives from experimental training and technical preparation. Many

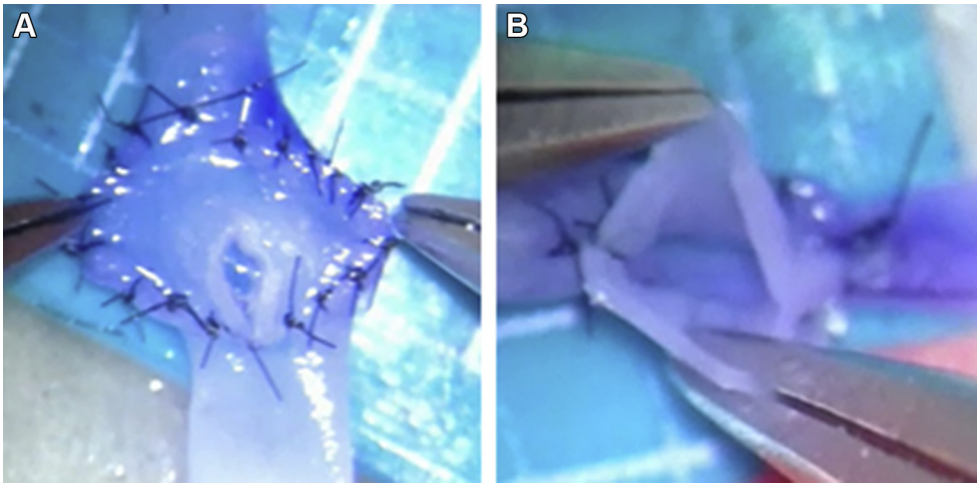

Figure 6. (**A**) Wide base of the bypass (good orifice). (**B**) Narrow base of the bypass (narrow orifice).

Table 1. Practical Scale for Evaluating the Quality of the Anastomosis

TSIO	Points
Closure time for 20 stitches in 1-mm vessel	
<20 minutes	1
>20 minutes	0
Good distribution of stitches	
Yes	1
No	0
Thread hidden inside lumen (intima-intima contact)	
Yes	1
No	0
Width of orifice (equal or wider than diameter of vessel)	
Yes	1
No	0

Practical scale (TSIO) for bypass training. The best score is 4. One point is awarded for closure time <20 minutes. For quality of the procedure, 1 point is awarded for good distribution of stitches; 1 point, for intima-intima contact (no thread is seen looking inside lumen); and 1 point, for having orifice equal or wider than diameter of vessel. Grade = [closure time <20 minutes] + [good distribution of stitches] + [not seeing thread inside lumen] + [width of orifice] (TSIO).
TSIO, time, stitch, intima, orifice.

factors with the potential to impact the quality of anastomosis cannot be evaluated directly during surgery in the operating room. A simple and experimentally applicable grading system that is designed to predict the quality and ability of the anastomosis to endure is proposed. The bypass should be graded according to the time taken to perform the anastomosis, the distribution of the stitches, the intimal attachment, and the size of the orifice. Ideally, an anastomosis bypass should be completed within 20 minutes and should have symmetric stitches, intimal attachment, and a wide orifice (**Video 1**).[18,19] The retrospective application of this grading scheme to a series of experimental bypass procedures was shown to accurately reflect the quality of anastomoses. The application of a standardized grading scheme would enable a comparison to be made of the results of various experimental bypass surgery training programs and between different surgical techniques and would assist with the development of hand-eye coordination.

Four variables (time, stitch, intima, orifice) were identified as useful for inclusion in the practical scale employed in this study to analyze 200 experimental end-to-side bypasses. The scale was simple to use (with an easy scoring system), was easily applied, and was predictive of anastomosis quality. The area under the receiver operating characteristic curve for was ≥70 for intima-intima attachment and for wide orifice (**Figure 7**). A significant difference between the use of interrupted or continuous suturing was not demonstrated in this study with respect to the impact of either on the quality of anastomosis. This is why both techniques are used by neurosurgeons.[5,11,20]

Time Taken to Perform Bypass

Ensuring that the vessel is closed quickly in a bypass procedure is stressful for the surgeon, as delays are associated with adverse brain effects. Although the performance and quality of the bypass are more relevant than stitching the vessels within the stipulated timeframe (of 20 minutes), the time taken to do so is used as a measure against which the speed at which improvement takes place is determined in training.[21,22]

Actions That Do Not Fulfill Their Objective and Time Taken to Perform Bypass

Actions that do not achieve their objective consume time and, more importantly, disturb the eye-hand orientation, flexibility, and self-confidence of the surgeon.[2,3,13,23,24] Although time is always measured during a bypass procedure, it is difficult to quantify the most optimal cutoff. The criterion of speed is not as important as the achievement of speed in combination with the other evaluated factors; that is, achieving a score of 1 for completing the procedure in ≤20 minutes is more valuable when combined with the other important criteria. Completing the procedure within ≤20 minutes impacted the technical ability learning curve. In this study, the procedure was completed more quickly using continuous rather than interrupted suturing (mean of 16.3 minutes vs. 19.9 minutes) (**Figures 5** and **6**).

Distribution of Stitches

Distribution of the stitches was predictable using the scale. Knotting each stitch in place, 1 at a time, using interrupted suturing helped with the equitable distribution of stitches along the vessel wall. Furthermore, the relationship between the donor and recipient vessel was established from the first 2 stitches and was maintained with the addition of each stitch (**Figure 1** and **Video 1**). By contrast, tightening the loose spiral suture and stretch suturing run as well as overtightening the end before tying to close the gap between the 2 edges to prevent leakage alters the relationship between the stitches on both sides. Neurosurgeons who use continuous suturing tend to apply an excess of stitches to avoid leakage at the end. However, they also take more time to carefully tighten each stitch in place at the end, which can improve stitch matching between the donor and the recipient vessel. Additional challenges of this technique occur when a broken suture is inserted in the middle of a continuous suture line, which requires extra work to repair, or when the wall tears, leaving a gap that needs to be fixed at the end using extra interrupted stitches.

Intimal Attachment

Ensuring intimal attachment is vital but cannot be evaluated during real-life surgery. The goal is to ensure that the thread is embedded inside the vessel wall (i.e., cannot be seen). This could have long-term consequences. For example, stasis and thrombosis can result from direct contact between the suture material and the blood.[25,26] This factor can be assessed only in an experimental bypass. On completion of the procedure, the donor vessel is cut close to the suture line. The inside of the lumen is then examined to determine if the thread can be seen in any of the stitches (**Figure 5B** and **Video 1**). The walls of the vessels have to flip out (invert technique) to achieve tight

Table 2. Characteristics of Sample and Score Result of 200 Training Bypasses According to the Practical Scale

	100 Bypasses on Wet Tube (1-mm Tube, 20 Stitches)				100 Bypasses on Chicken Wing (1-mm Vessel, 20 Stitches)			
	Interrupted Stitches (n = 50)		Continuous Stitches (n = 50)		Interrupted Stitches (n = 50)		Continuous Stitches (n = 50)	
	Vertical Recipient (n = 25)	Horizontal Recipient (n = 25)	Vertical Recipient (n = 25)	Horizontal Recipient (n = 25)	Vertical Recipient (n = 25)	Horizontal Recipient (n = 25)	Vertical Recipient (n = 25)	Horizontal Recipient (n = 25)
Closure time for 20 stitches in 1-mm vessel								
>20 minutes	13 (52%)	12 (48%)	1 (4%)	0	6 (24%)	7 (28%)	0	0
<20 minutes	12 (48%)	13 (52%)	24 (96%)	25 (100%)	19 (76%)	18 (72%)	25 (100%)	25 (100%)
Good distribution of stitches								
Yes	18 (72%)	21 (84%)	17 (68%)	19 (76%)	100 (100%)	23 (92%)	19 (76%)	17 (64%)
No	7 (28%)	4 (16%)	8 (32%)	6 (24%)	0	2 (8%)	6 (24%)	8 (32%)
Thread hidden (intima-intima contact)								
Yes	13 (52%)	18 (72%)	9 (36%)	16 (64%)	17 (68%)	20 (80%)	21 (84%)	19 (76%)
No	12 (48%)	7 (28%)	16 (64%)	9 (36%)	8 (32%)	5 (20%)	4 (16%)	6 (24%)
Size of orifice (equal or wider than diameter of vessel)								
Yes	23 (92%)	24 (96%)	16 (64%)	19 (76%)	24 (96%)	25 (100%)	23 (92%)	20 (80%)
No	2 (8%)	1 (4%)	9 (36%)	6 (24%)	1 (4%)	0	2 (8%)	5 (20%)
Score according to the practical scale								
4	6 (24%)	7 (28%)	6 (24%)	12 (48%)	13 (52%)	16 (64%)	15 (60%)	13 (48%)
3	8 (32%)	12 (48%)	7 (28%)	7 (28%)	9 (36%)	5 (20%)	5 (20%)	7 (32%)
4	7 (28%)	5 (20%)	9 (36%)	4 (16%)	3 (12%)	3 (12%)	1 (4%)	3 (4%)
1	4 (12%)	1 (4%)	3 (8%)	2 (8%)	0	1 (4%)	0*	2
Estimated good outcome (3 and 4)								
3 and 4	14 (56%)	19 (76%)	13 (52%)	19 (76%)	22 (88%)	21 (84%)	20 (80%)	20 (80%)

Related information of bypass anastomosis in 200 recorded samples and score according to the practical scale. A favorable result is defined as a score of 3 or 4.
*In a few cases (<5%), ≥2 of 5 of the observers could not give a definite evaluation for certain elements from the figures. In these cases, the judgment was done by going back to the recorded video.

intima-intima attachment, which is the goal so that the thread is not visible inside the lumen. Following an evaluation of several bypass surgeries and available materials, it was found in this study that interrupted suturing was able to successfully achieve intimal attachment without scarifying the size of the orifice.

Table 3. Negative Findings of 200 Bypass Procedures

	Closure Time >20 Minutes	Bad Distribution of Stitches	Thread Inside Lumen	Orifice Narrower than Vessel
Number of cases	39 (19%)	41 (21%)	67 (34%)	26 (13%)
Interrupted stitch	38 (97%)	13 (32%)	32 (48%)	4 (15%)
Continuous stitch	1 (3%)	28 (68%)	35 (52%)	22 (85%)

Gross analysis between the surgical technique and negative result of the survey for the 4 elements of the practical scale.

Table 4. Factors Significantly Associated with Favorable Outcome in Multiple Logistic Regression Model (Wald Stepwise Backward Model)

Factor	*P* Value	OR	95% CI
Intima-intima attachment	<0.001	31.82	10.30–98.28
Large orifice size	<0.001	55.30	10.94–279.68

OR, odds ratio; CI, confidence interval.

Orifice Size

It is possible to estimate the size of the bypass opening, or orifice, during real-life surgery. Blood flow through the orifice can be gauged using indocyanine green, microvascular Doppler imaging, or intraoperative angiography. Nevertheless, it cannot determine the real size of the orifice. Ensuring the dimensions of the orifice in relation to the diameter of the vessel is a good approach to ensuring the future success of anastomosis. Our data showed a correlation between the surgical technique and the size of the orifice. It was convenient to apply a "tent construction technique" (Video 1) using interrupted suturing by starting at the donor vessel and moving to the recipient vessel. An association was observed between the distribution of stitches, intimal attachment, and orifice size.

Use of Proposed Practical Scale

The technical difficulties of performing individual bypasses were highlighted by the proposed scale. Virtually all bypasses were completed without much difficulty using training of a reasonable level. However, greater attention and extra time were often required to effect wet tube and axis positioning of the recipient vessels.

This scale was designed to predict the outcome of a real-life bypass based on the level of skill executed during experimental anastomosis. Laboratory testing is accepted as the gold standard when performing a bypass, as it is the only means of estimating surgical ability and the risk of real-life anastomosis failure.[21] Repeating the anastomosis adds extra difficulty to the procedure, and most patients experience a stroke or worsening neurologic deficits in a short time.[27,28] Unfit bypass also fails to

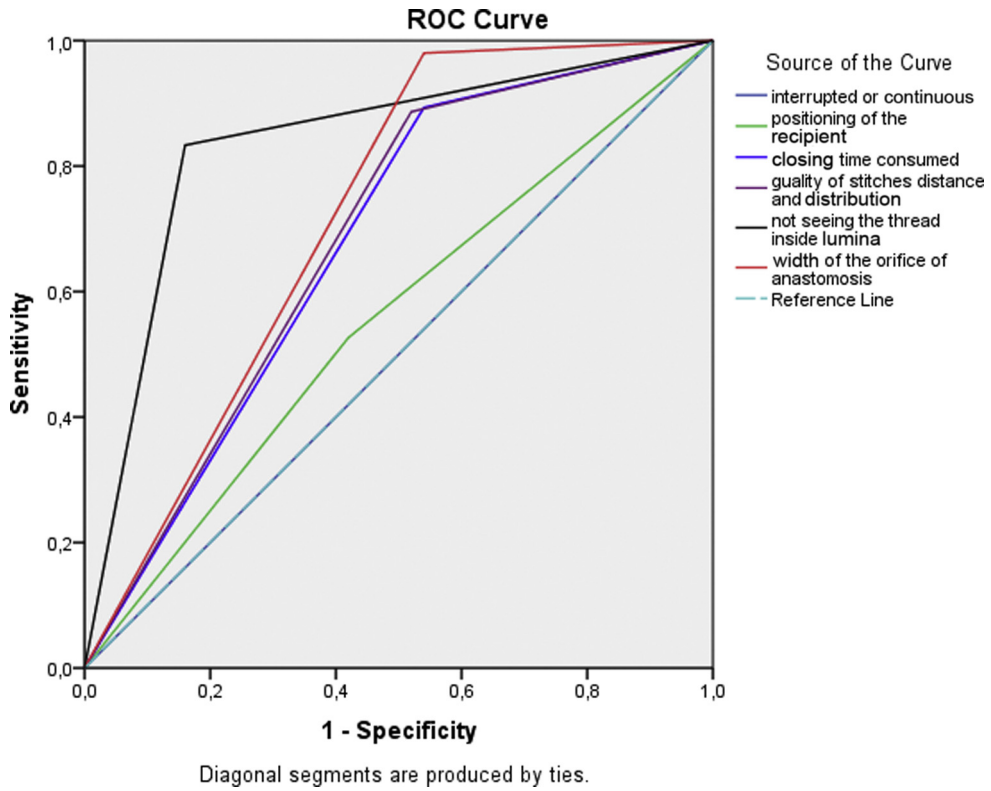

Figure 7. Results of the test of the area under the curve: interrupted or continuous suturing technique, 0.500; positioning of the recipient, 0.553; time to closure, 0.677; quality of stitches distance and distribution, 0.683; not seeing the thread inside lumen, 0.837; width of the orifice, 0.720. Interrupted light green line, reference line; light blue line overlapping reference line, interrupted or continuous suturing technique; green line, positioning of recipient; blue line, time to closure (closing time consumed); purple line, distribution of stitches; red line, orifice size; black line, intima-intima attachment. ROC, receiver operating characteristic.

provide protection from subsequent complications.[29] Even in cases in which intraoperative patency of the anastomosis has been demonstrated, there is no assurance that occlusion will not occur in the future. In such cases, the potential for delayed occlusion of the bypass exists.

The proposed grading scale can be applied to different types of anastomosis (i.e., end-to-side, side-to-side, and end-to-end). However, it is possible that this scale will not accurately predict the results of these 3 types of anastomosis at the same level, as the related techniques differ, and their performance differs among neurosurgeons. To improve performance based on the identified factors, several recommendations are offered regarding the development of hand skills, the reduction of unnecessary actions, and the achievement of stress free performance (**Video 1**). The prospective application of this grading scale in experimental bypass anastomosis is currently being considered. If this scale, in its simplicity, is capable of predicting anastomosis quality in other training-based studies, it will be a useful tool for evaluation of anastomosis quality, with a view to improving performance in real-life bypasses.

Limitations

This study has some limitations. It could be argued that consensus regarding good distribution of stitches is subjective. However, the same procedures were performed for all cases by the same reviewers, and the same images were seen using the same magnification. Greater objectivity was possible when evaluating whether or not the thread could be seen inside the lumen and when determining the orifice diameter against the vessel diameter. Nevertheless, consensus was reached in this regard as well as for all the factors for the vast majority of samples. Theoretically, the use of 1 neurosurgeon could have affected the ability to generalize the findings. However, this was necessitated by the study aim and the need to develop a scale to decrease any confounding factors.

CONCLUSIONS

The present study demonstrates the applicability of a practical scale for measuring and improving performance. It provides opportunities for trainees to acquire and practice their skill in a realistic environment. The 2 main suture techniques (continuous and interrupted) showed similar final results according to our scale, although with a different distribution of the related factors.

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