Using Engineering Methods (Kaizen and Micromovements Science) to Improve and Provide Evidence Regarding Microsurgical Hand Skills

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■ OBJECTIVE: **Microsurgical interventions involve the interaction of numerous variables, making objective analysis of skill proficiency challenging. This difficulty is even more pronounced in low-resource contexts. Continuous improvement methodologies such as Kaizen-planning, doing, checking, acting (PDCA) and micromovements science (MMS) can address this issue. This study aimed to demonstrate the advantages of designing and implementing microsurgical training programs using these methodologies.**

■ METHODS: **Following an extensive literature review of Kaizen-PDCA and MMS, and under the guidance of experienced neurosurgeons and engineers, a microvascular bypass training program was developed using the human placenta. Subsequently, the training program was used to analyze and describe the process of a trainee neurosurgeon in Argentina with no prior experience in microvascular anastomosis, as the operator gained proficiency.**

■ RESULTS: **The trainee required 12 attempts to achieve the program goals. The longest procedural time was during the first attempt (1 hour 49 minutes 05 seconds with 2 mistakes), while the shortest time was during the fourth attempt (53 minutes 29 seconds with 3 mistakes). After 12 attempts, the trainee made no mistakes, and the procedural time was reduced to 57 minutes 37 seconds. The final learning curve demonstrated a regular pattern and reached a plateau after 7 attempts.**

■ CONCLUSIONS: **The training program and methodology effectively assessed, facilitated, and demonstrated the acquisition of microsurgical skills. Kaizen-PDCA and MMS enabled the effective use of expert experience, detailed evaluation of microsurgical procedures, and integration into a continuous improvement cycle. The program structure could also be valuable for teaching, evaluating, and enhancing similar surgical procedures.**

INTRODUCTION

The core concept of a procedure can be defined as a “logical sequence of actions leading to a goal.” In the surgical field, a procedure consists of a series of surgical maneuvers (logical sequences of actions) aimed at solving a problem caused by a disease (goal).

Surgical procedures integrate heterogeneous variables from different fields such as anatomy, technique, pathology, clinical situation, and operating room team/infrastructure. These variables must be categorized according to urgency, type, body system involved, degree of invasiveness, and special instrumentation.[1]

When evaluating results, surgical procedures should aim to be better, faster, easier, safer, and cheaper. In other words, the procedure should evolve into a more effective version, and when possible, continue this improvement pathway by adapting to new ideas, technologies, and knowledge.

Key words
- Hand skills training
- Kaizen method
- Micromovements analysis
- Microscopic surgery

Abbreviations and Acronyms
CD: Coefficient of determination
MMS: Micromovements study
PDCA: Planning, doing, checking, acting
SD: Standard deviation

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Although achieving this goal is challenging owing to regular variability (which means that the same procedure has numerous regular variations, making standardization difficult), selected methodologies such as Kaizen-planning, doing, checking, acting (PDCA) allow effective integration of different components. In the following paragraphs, a brief but comprehensive justification is presented regarding the inclusion of engineering tools and methods combined with microsurgical procedures and their constant and rapid evolution.

The Kaizen-PDCA Method

After World War II, a theory was presented with the publication of "Kaizen: The Key to Japan's Competitive Success" by Masaaki Imai (1986) to the scientific community.[2] The core of this new perspective, oriented to properly diagnose and accurately solve problems, is known as the PDCA cycle (an acronym for Planning, Doing, Checking, Acting) (Figure 1). Sometimes, as mentioned by Gabran and Swartz, "Acting" is replaced by "Adjusting."[3] By using this cycle, data and practical experience are processed, allowing procedures to be standardized dynamically and always aimed at a fundamental concept: continuous improvement.

The Japanese experience has demonstrated its effectiveness in many areas,[4-6] promoting the use of this method in Western countries. The first documented applications of Kaizen in the health care sector were reported in the 1990s.[7,8] This approach has been widely used by numerous hospitals aiming for standardization or quality improvement.[3]

Some of the current applications can be reviewed using the references of this article: operating room functioning,[9] equipment utilization,[10] surgical equipment manufacturing,[11] and general health care.[12,13] Kaizen-PDCA has local institutions that provide professional counseling.[14] Recently, the National Institute for Industrial Technology (INTI, Argentina) and the Argentinian Society for Continuous Improvement (SAMECO, Argentina) found the method suitable to assess microsurgical procedures.[15]

The implementation of Kaizen in the health care sector can be very challenging.[12,16,17] However, when applying this method to microsurgical procedures, early and strong benefits were observed.

a) Effective use of the operator's cumulative experience (maximizing expert operator expertise).

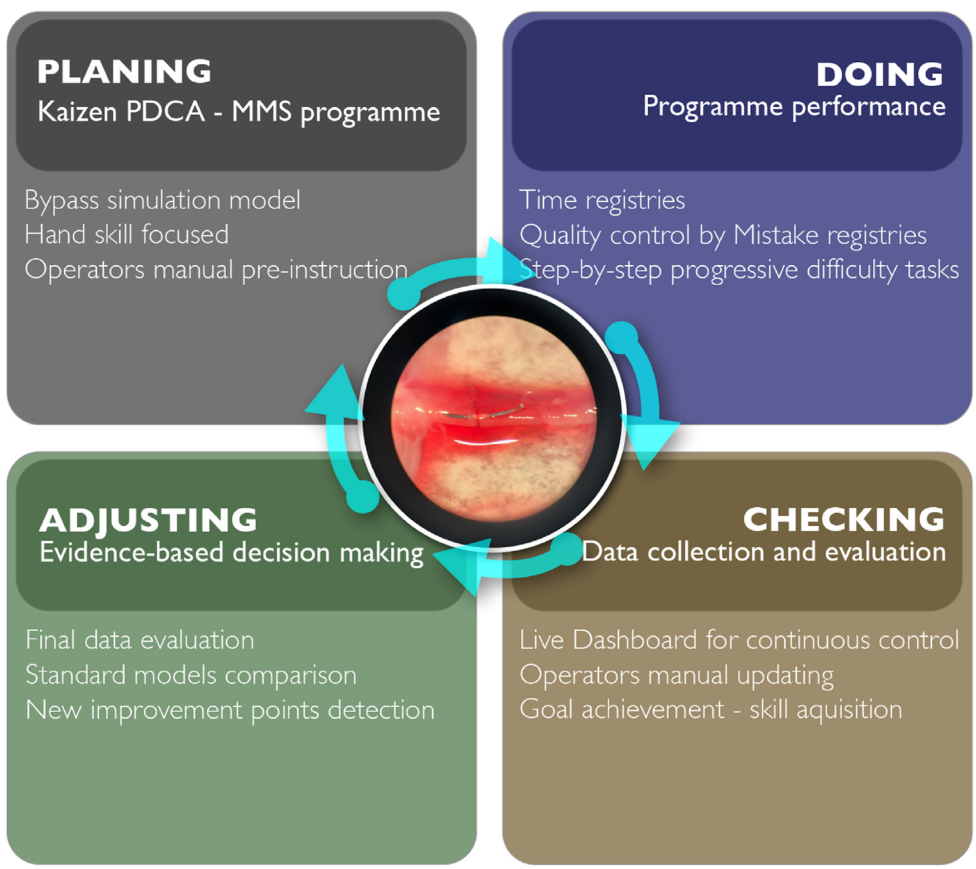

Figure 1. Kaizen PDCA cycle applied to a microsurgical situation. Source: own elaboration.

b) Deep process analysis, identifying significant variables.

c) Objective selection (sometimes even creation) of measurement tools.

d) Accurate stratification of procedure tasks and steps.

e) Creation of a "procedure dashboard" to obtain live data during procedure performance.

f) Ability to adapt to new strategies, devices, instruments, etc.

The Micromovements Study Theory

In the engineering field, micromovements study (MMS) theory and techniques have helped improve the efficiency of hand-skill-related procedures. Professors Lillian and Frank Gilbreth refer to this branch of science as the art of eliminating wastefulness due to unnecessary motions.[18] Further studies in this area have linked micromotions analysis with reduced fatigue, better posture, and time standardization for known procedures.[19]

Studying micromovements is optimal for evaluating small hand movements that are repeated several times during a procedure and also requires segmental analytics (from complex gestures to fundamental moves). These elemental micromovements (later called "Therbligs") become the nucleus of study for MMS and explain why an experienced operator achieves better results in terms of time and quality. MMS not only applies to movement evaluation, but also to how the training of a procedure should be divided into 3 main parts synchronized with the different categories of Bloom's taxonomy.[20,21]

It is important to mention that all the information from this area was used to analyze microsurgical gestures, enrich the "operator's manual," and design the task program. At the time of this study, we could not find any records linking MMS to microsurgical procedures.

The Relevance of Hand Skills Training at Higher Levels

"Serendipity or not, these surgeons (at a training laboratory) realized a marked improvement in their overall surgical technique and finesse once back in the operating room. A short time away from the patient spent in the laboratory enhanced and expedited the journey towards mastery of microsurgical techniques. This introduced the art of the paucity of undesired motion in the performance of surgery, and thus, the philosophy of ideal force and tool motion." (Prof. Dr. G. Sutherland, "Mastering intracranial microvascular anastomose" prologue).[22]

The surgical field has been evolving since the very beginning, with significant milestones such as the 1950s introduction of the operating microscope by Jacobson and Suarez to solve complex blood vessel anastomosis,[23] which defined microsurgery as a distinct surgical branch for many specialties.[24] For neurosurgeons, professor Yasargil and others set some of the core concepts of microneurosurgery 5 null decades ago.[25]

The expertise and skills gained during this period are now being challenged by advanced levels of visual magnification and digital imaging devices,[26-28] pushing hand-eye coordination to its limits. Thus, improvements in "hand skills at high levels of magnification" have a significant correlation with improvements in surgical outcomes.

In Argentina, the first author's country, there are few resources (such as devices, training institutions, artificial simulators, textbooks, and instruments), and there is an increasing need for skilled microsurgical operators. Therefore, mastering and educating microsurgical skills is both a significant challenge and a crucial area for improvement. Based on this background, we propose embedding the Kaizen-PDCA and MMS concepts into a microsurgical skill training program to find the minimum infrastructure needed for efficient surgical education. We analyzed and described the entire process of gaining proficiency during the program (in the hands of a neurosurgeon trainee), thereby validating its utility.

MATERIALS AND METHODS

Development of Kaizen-MMS Based Microsurgical Training Program

The Kaizen-PDCA system provides a start point and infrastructure to design, run, and evaluate a program as follows:[15]

Planning

a. Background information: Books and papers were reviewed using specific keywords: "surgical training," "surgical learning curves," "microsurgical techniques," "microsurgical devices," "Kaizen in surgery," "microsurgical simulators," "continuous improvement methods," and "micromovements evaluation."

b. Improvement points detection: Experts at microsurgical interventions (members of the Neurosurgical Department at KIMS Karad University, India) discussed the information and selected "the need for skilled surgeons at complex microsurgery" as the main point to improve.

c. Precise problem definition: "The need for continuous improvement of microsurgical skills at a high level of magnification" was then analyzed to find possible causes, using a Brainstorming technique; results were organized using Ishikawa cause-effect diagram, and finally weighed by Pareto's diagram to identify the most important variables to be focused on. Later, using 5W1H technique (what, why, where, who, when, how) for every principal cause, an action plan was depicted with the following directives:

   - To use a surgical simulator.
   - To build a precise step-by-step program to standardize the procedure.
   - To use the experience of most experts (building an operator manual).
   - To identify variables that properly evaluate dexterity (hand skills assessment).
   - To choose or generate tools for precise measurements (scores tables).
   - To verify effectiveness of the proposed plan (statistical evaluation).

d. Main program goal: Hand skill improvement using a dedicated program (step-by-step evaluation of specially designed tasks), with objective quality assessment (less time used and fewer mistakes committed) in a controlled scenario.

- Doing (sequential logical tasks): The starting point was learning from the accumulative experience of experts in the field using an operator's manual (specially written for this purpose, **Appendix 1**), where specific strategies, gestures, and tips were offered to the operator. The MMS enriched this analysis and teaching stage. The program was then performed, following tasks and goals designed to develop high dexterity levels for tissue interaction, instrument manipulation, and device application.
- Checking: Selected hand skill-focused variables (elapsed time, mistake score, and level of magnification) allowed for the construction of a control panel with real-time information, offering the opportunity to supervise strategies and technical issues.
- Action/Adjusting: Real-time reading and interpretation of information from the control panel allowed early decision-making when the results displayed significant variations. In addition, the operator's manual was constantly evaluated to enrich the content for other operators and/or future samples for the same operator (this last adjustment assured fluency and practice-update of the procedure's basis).

Task Program Design

A step-by-step progressive complexity task program modality was adopted for better engagement in hand skills training. Full comprehension of the operator's manual was assessed as a *sine-qua-non* requirement for initiating the program. The task and step details are given in **Appendix 2**.

The human placenta was selected as the biological simulator owing to its known benefits, academic background, and inexpensive accessibility (**Appendix 2**).[29-38] The simulator was carefully preserved[39,40] until being used. Then, it was placed on a flat surface under a microscope to achieve optimal lighting conditions and minimize any potential bias related to angle, position, or comfort.

The operation scenario was set under a surgical microscope with standard features (working distance 25 cm, hand positioning, 6X-10X-16X-25X-40X optical magnification changer, LED light, 10X ocular pieces). A classical instrument set was consistently used (2 microforceps, 1 vessel dilator forceps, 1 curved needle holder, 2 microscissors, and rulers) for all procedures. The sutures, as required by the task, were a Mononylon 10/0, vascular 6 mm - 3/8 circled needle (always the same brand provider). The same operating conditions were used for all samples. Stopwatches and digital online annotations were also used.

The task complexity was increased progressively according to the smaller size of the elements to be manipulated, requested maneuver difficulty, and magnification level required. The magnification level should be selected to achieve a balance between comfort and proper tissue visualization and handling. Suggested levels were defined as low-level magnification (up to 10X), midlevel magnification (10-20X), or high level magnification (>20X) following the descriptions and specially made recommendations in the operator's manual.

Each task was repeated as many times as necessary to complete it without any mistakes before advancing to the next difficulty level. Tasks 1–4 were planned to serve as "warming-up" tasks, aiming to: be comfortable while working with the anatomy and particularities of the surgical simulator, being familiar with the program, and having a smooth interaction with the working unit (microscope features, instrument set). In these tasks (1–4), time registries were allowed to provide feedback to the operator, but they did not participate in building the final database.

Assessment of Surgical Skill and Feedback

Focused variables were measured using specific tools and rules.

1. Time elapsed: The clock (stopwatch showing minutes and seconds) was started and stopped following each task indication. No stopping was allowed for any reason. Time was interpreted as having a close inverse relationship with performance dexterity (better skill, less time used).
2. Mistakes made: A mistake scoring system was proposed and followed for all tasks (dissecting and suturing steps) in the program. Quick notes, such as "m" (minor mistake) or "M" (major mistake) were taken during task performance. Later, these notes were replaced by a numeric correlation system, aiming to further mathematically interpret and represent a quality evaluation for each step of the program.

A thorough description of each major and minor mistake was built (**Table 1**).

The vessel patency test was performed at the end of the suturing stage. This test consisted of cannulation of the proximal end of the

Table 1. Mistakes Scores, Explanation, and Nomenclature

Mistake Abbreviation, Name and Value	Description
"M" = Major mistake = 4pts	Selected vessel for dissection is damaged (bleeding from a wall break).
	Sutured vessel appears nonpermeable while testing it. Patency verification tests show nonflux or nonsignificant flux along though the suture line.
"m" = minor mistake = 1pt	Small braches coming from the parental vessel are cut, intentionally or not, instead of being avoided by fine dissection.
	Laminar chorionic membrane, the deeper layer under the vessel bottom, is breached. Bleeding from decidua levels appears.
	Sutured vessel shows a leak along the suture line (either between stitches, and/or, because a stitch started coming loose during the patency test).

This table summarizes all the possible mistakes committed during the task's performance, giving a numeric value to be objectivized, aiming to formal database building. Mistakes will appear at the surgical field as "bleeding" (during dissection), "leak," or "occlusion" (the last 2 come from patency test observation).

sutured vessel using an insulin (G30) needle with a 1 mL syringe filled with saline. Pressure was then slowly and manually applied to the syringe to look for 1) vessel patency through the suture line and 2) suture line stability and sealing. This allowed the operator to properly classify the suture quality and annotate the mistake score for this step of the task.

Only Task 5 was used for database building and further analysis, particularly for time records (mandatory for this task). To set the working scenario under the same conditions for all the samples (so that the evaluation focus could be placed on hand skills only), only 1 operator (surgeon) performed the entire program.

A registration form was proposed for this task to facilitate the subsequent database building (Table 2).

Inclusion and exclusion criteria should be evaluated to filter low-quality data, prioritizing the quality of the procedure.

Inclusion Criteria. Every task performed, accomplishing goals, and not matching any of the exclusion criteria (see below).

Exclusion Criteria. Any task performed, reaching the maximum mistake level, AND/OR, any interruption made between steps, and demanding to stop the clock before each step indication.

After completing the full-task program, the neurosurgeon trainee's data from these forms were collected in a digital online spreadsheet, as planned.

Statistical Analysis

While studying the program-focused variables, a descriptive statistical method was used to summarize and better observe the acquired data.

Time-elapsed values and consequent slopes were studied in detail using multiple data segregations (by expertise and steps of the task). The average time was calculated and an exponentially shaped learning curve was generated. The variability in the expected results was analyzed. Nonparametric proofs accompanied each interpretation owing to the heterogeneous variance origin.

Table 2. Registration Form for Data Registration

Date	Placenta n°	
Step Name	Time Elapsed (Mm-ss)	Mistakes Made (M or m)
Vein dissection		
Artery 1 dissection		
Artery 2 dissection		
Suture		

This table aims to collect all possible variables during the task's data registration. Step-by-step segregation aims to determine each partial goal achievement and detect where the mistake was committed. Besides its main goal (serving as a data source for a computed database system), a quick view of this form allows a supervisor to know about the task performance results, quality and need for technical assistance or strategy modification.

A regression analysis was performed. A nonconstant variance was identified, making the analysis of variance test inappropriate for this instance (in this respect, see further comments in the Discussion section).

RESULTS

Full raw data registers were collected and are presented in Table 3.

Twelve placentas or procedures were required to perform Task 5 without any mistakes. One procedure (between placentas 4 and 5) was excluded because it met the exclusion criteria. Each placental sample was subjected to a single procedure. Therefore, different attempts corresponded to different placentas.

Every sample that met the inclusion criteria but not the exclusion criteria (n = 11) were used to represent the evolution of "time elapsed" variable.

The longest attempt was the first 1, accounting 1 hour 49 minutes 05 seconds. The shortest attempt was the fourth one, accounting 53 minutes 29 seconds (3 mistakes [M + m + m] for a 6-points mistake value). The time required to perform this task with no mistakes was 57 minutes 37 seconds (last attempt). The total time spent working on Task 5 was 13 hour 47 minutes 03 seconds (12 placentas). The average time required for this task was 1 hour 15 minutes 11 seconds.

Mixing elapsed time and mistake level variables in Figure 2 is showing how the time and mistake variables interacted. After 3 attempts, there was a significant decrease in time (shortest time of the series, placenta number 4); however, mistakes also reached a maximum level, showing a peak at the same point. The next sample was followed by 1 attempt with even more mistakes; thus, it was discarded as it met the exclusion criteria (between placenta numbers 4 and 5; further details in the Discussion section).

Similar proportions can be observed in the steps of different attempts of Task 5 (Table 3).

Low dispersion levels were obtained for each attempt by calculating the trend line (Figure 3).

The time required to accomplish the task was significantly shorter for the more experienced operator (Figures 4–6).

The final goal of achieving the zero mistake level for Task 5 was achieved after 12 attempts.

DISCUSSION

The surgical procedures and training have always been a challenging topic. The surgeon's skills and his/her learning process (represented by learning curves)[41-44] are crucial features to analyze and evaluate when looking for a good procedure/operator relationship.

Aiming for minacious and renewed evaluation, a multidisciplinary group (engineers and health care providers) was recruited from the Argentinian Society of Continuous Improvement, 'SAMECO', Salta city National University – Argentina, Hokkaido University Hospital – Japan, Krishna Institute of Medical Science – India, and National Institute of Industrial Technology 'INTI' - Argentina. At this point, mixed knowledge and methods from microsurgery and continuous improvement science started to work as the main engine of this program.[15,38]

Table 3. Full Raw-Data Collected From the Registration Form (for Task 5 Performance)

STEP	Placenta 1		Placenta 2		Placenta 3		Placenta 4		Placenta 5		Placenta 6		Placenta 7		Placenta 8		Placenta 9		Placenta 10		Placenta 11	
	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X	T	X
Vein dissection	0:43:29	1	0:33:29	0	0:27:37	0	0:10:27	1M	00:32:01	0	00:23:40	1	00:23:26	1	00:23:28	0	00:14:00	0	00:15:30	1	00:15:37	0
Artery 1 dissection	0:19:19	1	0:24:15	0	0:16:18	0	0:10:31	0	0:13:30	0	0:12:35	0	0:13:07	1M	0:10:53	0	0:13:16	0	0:08:05	0	0:09:56	0
Artery 2 dissection	0:16:01	0	0:17:18	0	0:06:26	0	0:10:27	0	0:13:05	0	0:12:19	0	0:10:52	0	0:07:14	0	0:10:55	0	0:06:40	0	0:04:50	0
Suture	0:30:15	2	0:25:25	2	0:38:38	2	0:22:04	2	0:26:12	2	0:33:15	2	0:25:54	1	0:18:23	2	0:23:37	1	0:25:30	2	0:27:14	0
Total	1:49:04	4	1:40:27	2	1:28:59	2	0:53:29	6	1:24:48	2	1:21:49	3	1:13:19	5	0:59:58	2	1:01:48	1	0:55:45	3	0:57:37	0

(T) column = time. (X) column = mistake's score qualification.
Minor mistakes will appear as a number indicating how many times a minor mistake was committed. When a Major mistake needs to be registered, the number will be followed by an "M" letter. The TOTAL row shows the total task time (hours:minutes:seconds) and the total mistake score (Major mistakes accounting 4 pts/Minor mistakes accounting 1 pt). Special mention: 1 sample was discarded (between placenta 4 and 5) because the procedure met the exclusion criteria (too many mistakes committed, score >6pts).

The continuous improvement science is already being used for many medical care-related topics[45-47]; however, no previous records of Kaizen for surgical procedures were found.

The mentioned Kaizen-PDCA and MMS methodologies, while performing this program, made it easy to.

- Choose the most significant and sensible variables to better show performance evolution (serving as live feedback and helping decide strategy changes; see **Figure 2** and interpretation).
- Take precise/objective measures by generating dedicated tools (i.e., "mistake score" — **Table 1**).
- Detect and clarify poorly defined concepts, such as "magnification level" (see "operator manual").
- Concentrate experts' operator experience by generating and using a procedure-specific "operator manual", enriched with MMS analysis, and placing it in a continuous improvement pathway.
- Maintain objectiveness and structure, as well as flexibility to interact with new concepts (changing strategies, new ideas, updated information, new evidence, etc.).
- Precisely isolate and resume valuable information from a complex situation and show it on a live dashboard.
- Select an indispensable infrastructure to design and perform a training program, with special care to be accessible and useful in a low-resource scenario.

Statistical Analysis and Interpretation

The first observation shows an objective relationship between the time elapsed and expertise; the time elapsed significantly diminished in later attempts. This situation was interpreted as "learning" or "gaining skills" while performing the program (**Figure 2**).

The mistake level showed alternating changes, with a general tendency to lower mistake scores (reaching zero level as the final goal). Reading mistake values, an alert was inferred on the live-dashboard, detecting a particular situation: a mistake peaked at the fastest sample (sample 4 in **Figure 2**), followed by an excluded sample to reach the maximum mistake level. This data interpretation suggests the need for strategy modification by performing technical revisions and special care to avoid mistakes. This review resulted in an increase in time in the next attempt but with a plummeted mistake level (sample 5 in **Figure 2**).

A trend line was built using all trial's time-data, showing a "learning-curve" pattern,[41-43] with a plateau level after 7 attempts. The values for "time" show a mild and variable dispersion (blue dots above or below the line - **Figure 3**), probably caused by small technical differences (magnification level used, initial warming-up needed at the beginning of a task) or other external causes (sample differences, comfort while working, selected working position, selected vessel details like tortuosity, or the presence of small branches hindering dissection).

Next, full dataset was segregated by steps and variance behavior.

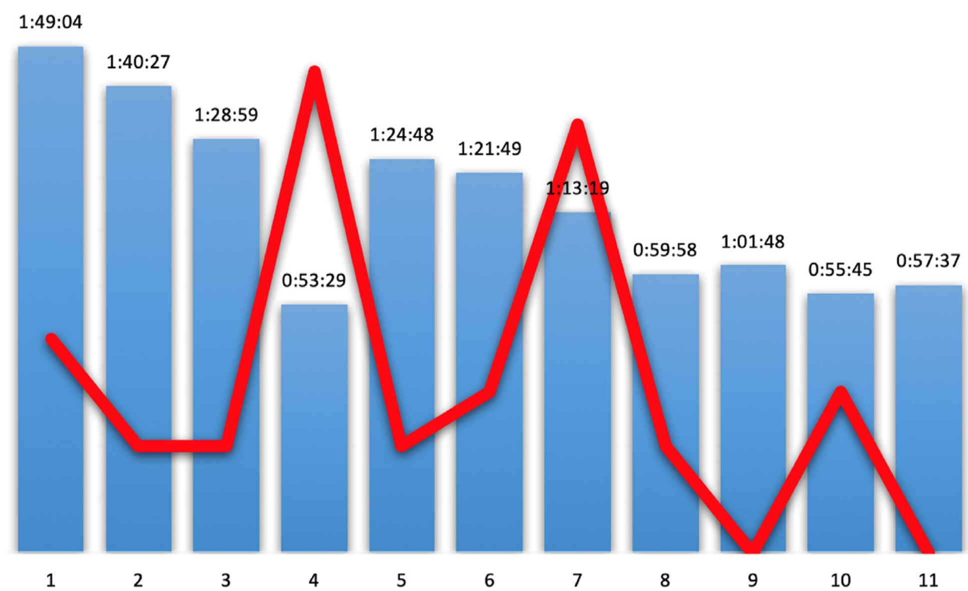

Figure 2. Time elapsed and mistakes for Task 5. Blue bars reveal the total time registered for each task attempt; red line is showing mistakes made in each attempt.

Segregation by step (**Table 3**) showed that artery dissection had a similar dissection time for artery 1 (orange) versus artery 2 (gray), but the dissection time for artery 2 was always shorter. Vein dissection (blue) was significantly more time consuming than arterial dissection and generated more mistakes. This last finding indicated that the vessel wall type was the main difficulty.

Segregation by variance behavior showed marked differences between the first 3 steps (with 'dissection' as the main goal — **Figure 4**) versus the fourth step (with a 'suture' goal — **Figure 5**), being interpreted as follows.

a) The 3 initial steps (dissecting steps) showed a more stable and favorable evolution (initial standard deviation [SD] value: 757.35; final SD value: 5.66).

b) The last step (suturing step) was the most time-consuming, unsettled, and the main source of mistakes. These features make this step the most challenging. Despite this, the performance still improved and the variance decreased in the last samples (initial SD: 327.61; final SD: 73.54), but presumably more attempts were needed to reach the desired levels.

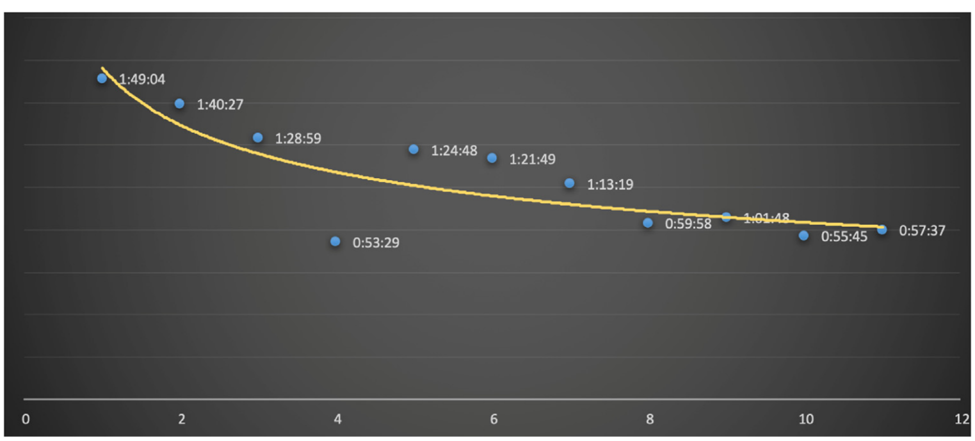

Figure 3. Calculated trend line (exponential). *Blue dots* for every attempt are showing dispersion level.

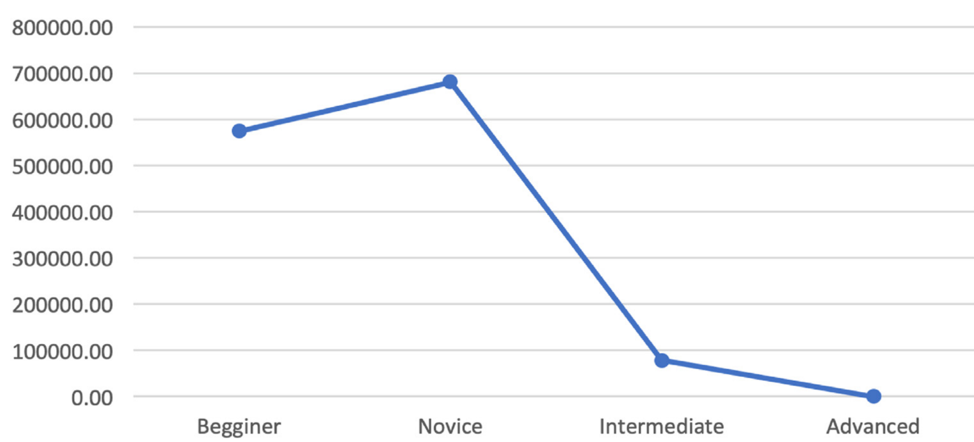

Figure 4. Variance in time to perform step 1–3, for grouped categories: beginner (samples 1–3), novice (samples 4–6), intermediate (7–9), advanced (10 and 11). Time is shown in seconds.

The evidenced differences between dissecting and suturing steps represent different situations and different skills. Particularly at this point, MMS knowledge could be further investigated: microsurgical therbligs could play a definitive role in this situation (suturing steps requested more complex movements, or "advanced therbligs," than dissecting steps). Some of the so called "advanced therbligs" could be those that include rotational moments (i.e., while passing the needle through the vessel wall), indirect tissue interaction (i.e., when the operator's hand manipulates an instrument [needle-holder] which holds a second element [needle] to finally interact with tissues), and/or both hand instruments interaction (i.e., taking the suture line through a loop, while making a knot). Although interesting, going deeper into this analysis requires further investigation and clearly exceeds the scope of this study.

It was interesting to see how the "Novice" took more average time than "Beginner," but this scenario corresponded to a high demand in quality after strategic revision (Figures 4 and 5). This situation, rather than confusing, could mean good sensitivity detecting significant variations, and good efficacy to show changes that require "strategic changes" during performance.

In Figure 6, an average line is constructed for the dissection steps. The dots for each average time are shown, with small dispersion (SD 5.66; coefficient of determination [CD] 0.92), showing a possible effect of training and supporting the expected results of the learning curve. The 0.92 CD value could

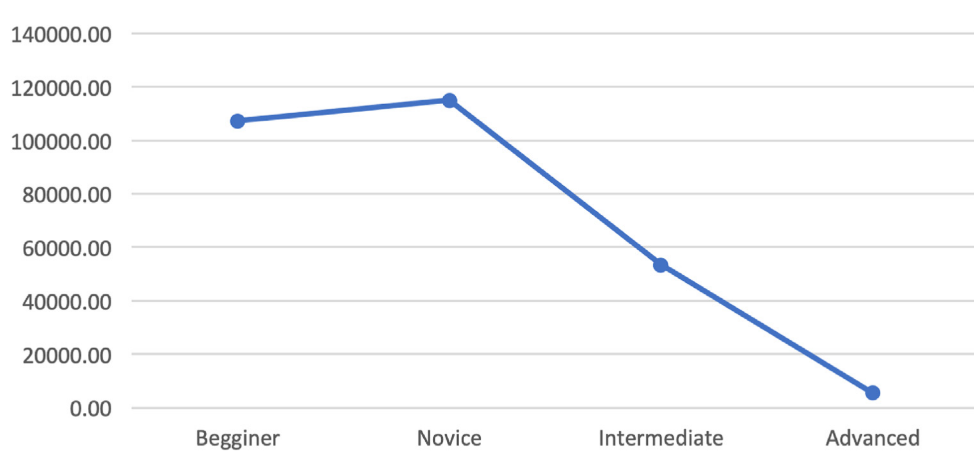

Figure 5. Variance in time to perform step 4, for grouped categories: beginner (samples 1–3), novice (samples 4–6), intermediate (7–9), advanced (10 and 11). Time is shown in seconds.

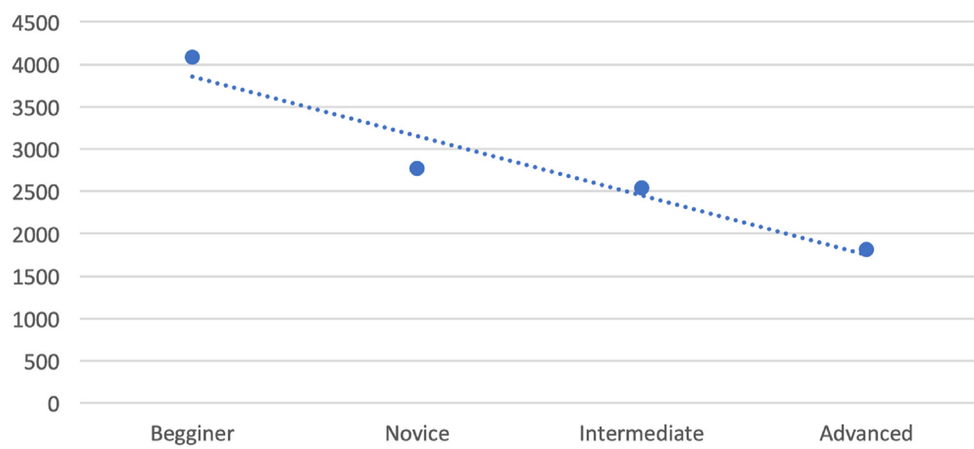

Figure 6. Average time for grouped categories. Beginner (samples 1–3), novice (samples 4–6), intermediate (7–9), and advanced (10 and 11). Time is shown in seconds. Trend line is shown as a dotted line ($R^2 = 0.92$).

also be interpreted as a good model to predict changes (a confident program to obtain the proposed goals).

In summary, statistical analysis proved good sensitivity while detecting technical changes (Figure 2, rise in time and lowering mistakes after strategy modification), good confidence levels for predicting evolution (represented in Figure 6 - CD 0.92), and good results while evaluating progress after a training period for the same operator (Figures 4 and 5, showing significant skill improvement between early/beginner vs. later/advanced operators).

Interestingly, each step with doubts or questions immediately became an "improvement situation" itself. Thus, beginning its own method of continuous improvement (PDCA cycle). This method acted as a self-improving point detector. Microsurgical hand skills were objectively assessed, improved, and evidenced by performing this program.

The structure of this training program may also be suitable for the evaluation and improvement of other surgical procedures, its effectiveness, comparison, instrument/strategy testing, operator's skills, etc. The method showed good data flow, with a live dashboard allowing the identification of critical situations. This is a valuable feature for teaching, research, and surgical supervision.

In addition, this program established a renewed/accurate view to assess surgical procedures, which could lead to further evolution (i.e., using proven procedure-evaluation methods, computed databases for the procedure's live data representation, augmented reality, technological demands, etc.).

Overall, good results were obtained using minimal infrastructure and an easy-to-access biological simulator. This feature is especially important in places where training centers are not easily accessible (e.g., high costs, lack of cadaveric samples, lack of biolaboratories, absence of facilities, and low-income environments).

Finally, continuous improvement of microsurgical quality could also indicate a continuous improvement in patient outcomes.

Program Limitations

- The "only 1 operator" situation was good for focusing on hand skills, but diminished extra corroboration for effectivity and confidence levels. The statistics team advised the need for bigger data volume and collecting data from more than 1 surgeon/operator as a way to be able to set an analysis of variance test.
- The "suturing stage" offered suboptimal results; however, these findings settled a base for a new "point of improvement" (beginning of a new Kaizen's cycle), especially involving MMS analysis and microsurgical teaching.
- Continuous improvement methods (such as Kaizen and MMS) were found to be suitable for microsurgical evaluation but required extra resources and formation.
- Important concepts like "microsurgical therbligs" and "surgical-data management" need further investigation and increased volumes of data to match the requested levels in this respect.

CONCLUSIONS

This training program promoted a significant decrease in time and controlled mistake levels in a microsurgical scenario, meeting the goal "assessing, training, and improving hand skills at high levels of magnification".

Building a dedicated, technically specific, and expert-updated operator manual represented a cornerstone for this program. This is in accordance with Kaizen's core recommendations for continuous improvement.

The resulting trend lines narrowly correspond to the classic "learning curve" effect for one-person progression (the first validation parameter for our program). The CD at the dissecting steps showed a good confidence rate (0.92), indicating the efficiency of the program in predicting changes (second validation parameter).

Similar results were obtained at the last stage, suturing vessels, but further practice/investigation is required to obtain the same confidence level.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Pablo Javier Villanueva: Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Taku Sugiyama:** Writing – review & editing, Supervision, Methodology, Formal analysis, Conceptualization. **Bárbara Magdalena Villanueva:** Methodology, Formal analysis. **Hector Ivan Rodriguez:** Validation, Formal analysis. **Antonio Arciénaga:** Supervision, Methodology, Formal analysis, Conceptualization. **Iype Cherian:** Conceptualization.

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REFERENCES

1. Grill C. State of the states: defining surgery. *Bull Am Coll Surg*. 2012;97:27-29.
2. Imai M. *Kaizen: The Key to Japan's Competitive Success*. 1st ed. New York: McGraw-Hill Education; 1986.
3. Gabran M, Swartz JE. *Healthcare Kaizen. Engaging Front-Line Staff in Sustainable Continuous Improvements*. Boca Raton, Fl: CRC Press; 2012.
4. Ullah MF, Fleming C, Fox C, Teward T, Tormey S. Patient experience in a surgical assessment unit following a closed-loop audit using a Kaizen Lean system. *Ir J Med Sci*. 2020;189:641-647.
5. Lordelo S, Nogueira S, de Farias Filho J, Costa H, Barbosa C, Calado R. Kaizen and healthcare: a bibliometric analysis. APMS 2021. IFIP Advances in Information and Communication Technology. In: Dolgui A, Bernard A, Lemoine D, von Cieminski G, Romero D, eds. *Advances in Production Management Systems. Artificial Intelligence for Sustainable and Resilient Production Systems*. Cham: Springer; 2021:; Vol. 631.
6. Smith ML, Wilkerson T, Grzybicki DM, Raab SS. The effect of a lean quality improvement implementation program on surgical pathology specimen accessioning and gross preparation error frequency. *Am J Clin Pathol*. 2012;138:367-373.
7. Smith R. Medicine's need for kaizen. *BMJ*. 1990;301:679-680.
8. Berwick DM. Continuous improvement as an ideal in healthcare. *N Engl J Med*. 1989;320:53-56.
9. DuraLabel. Kaizen: continuous improvement ideas for healthcare. Available at: https://www.graphicproducts.com/articles/kaizen-continuous-improvement-ideas-for-healthcare/. Accessed July 10, 2023.
10. Abuzied Y. A practical guide to the kaizen approach as a quality improvement tool. *Glob J Qual Saf Healthc*. 2021;5:79-81.
11. Gupta S, Chandna P. Implementation of kaizen a lean manufacturing tool in a surgical equipment manufacturing industry. *Int J Serv Oper Manag*. 2022;41:431-443.
12. Shatrov K, Pessina C, Huber K, Thomet B, Gutzeit A, Blankart CR. Improving health care from the bottom up: factors for the successful implementation of kaizen in acute care hospitals. *PLoS One*. 2021;16:e0257412.
13. Mazzocato P, Stenfors-Hayes T, von Thiele Schwarz U, Hasson H, Nyström ME. Kaizen practice in healthcare: a qualitative analysis of hospital employees' suggestions for improvement. *BMJ Open*. 2016;6:e012256.
14. Parenti A, Richard A, Strano F, et al., eds. *Emprendiendo Kaizen 1a ed [Internet] General*. San Martín: Instituto Nacional de Tecnología Industrial - INTI; 2019.
15. Villanueva P, Villanueva B, Sanmarco C, et al. *Kaizen - Engineering tools for the developement, evaluation, certification and continuous improvement of microsurgical abilities and procedures. MEDICINA EM FOCO EXPLORANDO OS AVANÇOS E AS FRONTEIRAS DO CONHECIMENTO*. Brasil: Seven Editora; 2023, 10.56238/medfocoexplconheci-049.
16. Smith G, Godwin AP, et al. Applying lean principles and kaizen rapid improvement events in public health practice. *J Publ Health Manag Pract*. 2012;18:52-54.
17. Hasegawa T, Karandagioda W. *Change Management for Hospitals — Through Stepwise Approach, 5S-KAIZEN-TQM*. 2nd ed. Tokyo: Japan International Cooperation Agency; 2013.
18. Sandhya Y, Promilakrishna C. Micro- motion study of worker. *Int J Res Public Rev*. 2022;3:3123-3129.
19. Guha S, Verma DS. Time and motion study in a manufacturing industry. *J Emerg Technol Innovat Res*. 2020;7:2066-2072.
20. Bloom BS. *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*. New York: David McKay Co Inc.; 1956.
21. Morlock F, Kreggenfeld N, Louw L, Kreimeier D, Kuhlenkötter B. Teaching methods-time measurement (MTM) for workplace design in learning factories. *Procedia Manuf*. 2017;9:369-375.
22. Sugiyama T. *Mastering Intracranial Microvascular Anastomoses - Basic Techniques and Surgical Pearls*. Osaka, Japan: Medicus Shuppan; 2017.
23. Barbary S, Dap F, Dautel G. Finger replantation: surgical technique and indications. *Chir Main*. 2013;32:363-372.
24. Shenaq SM, Klebuc MJ, Vargo D. Free-tissue transfer with the aid of loupe magnification: experience with 251 procedures. *Plast Reconstr Surg*. 1995;95:261-269.
25. Yaşargil MG. *Microsurgery*. 1st ed. Portland: Academic Press; 1969.
26. Belykh EG, Zhao X, Cavallo C, Bohl MA, Yagmurlu K, Aklinski JL. Laboratory evaluation of a robotic operative microscope - visualization platform for neurosurgery. *Cureus*. 2018;10:e3072.
27. Moisi MD, Hoang K, Tubbs RS, et al. Advancement of surgical visualization methods: comparison study between traditional microscopic surgery and a novel robotic optoelectronic visualization tool for spinal surgery. *World Neurosurg*. 2017;98:273-277.
28. Montemurro N, Scerrati A, Ricciardi L, Trevisi G. The exoscope in neurosurgery: an overview of the current literature of Intraoperative use in brain and spine surgery. *J Clin Med*. 2021;11:223.
29. Jansen CHJR, Kastelein AW, Kleinrouweler CE, et al. Development of placental abnormalities in location and anatomy. *Acta Obstet Gynecol Scand*. 2020;99:983-993.
30. Gray H. *Implantation and Placentation In: Gray's Anatomy*. 41th ed. London, England: Arcturus Publishing Ltd.; 2015:171-181.
31. Byvaltsev VA, Akshulakov SK, Polkin RA, et al. Microvascular anastomosis training in neurosurgery: a review. *Minim Invasive Surg*. 2018;2018:6130286.
32. Favaron PO, Carvalho RC, Borghesi J, Anunciação AR, Miglino MA. The amniotic membrane: development and potential applications. A review. *Reprod Domest Anim*. 2015;50:881-892.
33. Herrick EJ, Bordoni B. Embryology, Placenta. *StatPearls [Internet]*; 2023. Available at: https://www.ncbi.nlm.nih.gov/books/NBK551634/. Accessed February 20, 2023.
34. Romero FR, Fernandes ST, Chaddad-Neto F, Ramos JG, Campos JM, Oliveira E. Microsurgical techniques using human placenta. *Arq Neuropsiquiatr*. 2008;66:876-878.
35. Oliveira MM, Wendling L, Malheiros JA, et al. Human placenta simulator for intracranial-intracranial bypass: vascular anatomy and 5

bypass techniques. *World Neurosurg*. 2018;119:e694-e702.

36. De Oliveira MMR, Ferrarez CE, Ramos TM, et al. Learning brain aneurysm microsurgical skills in a human placenta model: predictive validity. *J Neurosurg*. 2018;128:846-852.

37. Ribeiro de Oliveira MM, Nicolato A, Santos M, et al. Face, content, and construct validity of human placenta as a haptic training tool in neurointerventional surgery. *J Neurosurg*. 2016;124:1238-1244.

38. Villanueva P. Sameco - surgical kaizen. Available at: https://drive.google.com/file/d/1qQjyD3QY332G7GoSGt_cjUMFk6ddxf5O/view?; 2020. Accessed February 20, 2023.

39. Ingemansson R, Budrikis A, Bolys R, Sjöberg T, Steen S. Effect of temperature in long-term preservation of vascular endothelial and smooth muscle function. *Ann Thorac Surg*. 1996;61:1413-1417.

40. Lou JJ, Mirsadraei L, Sanchez DE, et al. A review of room temperature storage of biospecimen tissue and nucleic acids for anatomic pathology laboratories and biorepositories. *Clin Biochem*. 2014;47:267-273.

41. Ramsay CR, Grant AM, Wallace SA, Garthwaite PH, Monk AF, Russell IT. Assessment of the learning curve in health technologies. A systematic review. *Int J Technol Assess Health Care*. 2000;16:1095-1108.

42. Ramsay CR, Grant AM, Wallace SA, Garthwaite PH, Monk AF, Russell IT. Statistical assessment of the learning curves of health technologies. *Health Technol Assess*. 2001;5:1-79.

43. Yelle LE. The learning curve: historical review and comprehensive survey. *Decis Sci J*. 1979;10:302-328.

44. Buchmann P, Dinçler S. Lernkurve berechnung und stellenwert in der laparoskopischen chirurgie. *Ther Umsch*. 2005;62:69-75.

45. Flug JA, Stellmaker JA, Sharpe RE Jr, et al. Kaizen process improvement in radiology: primer for creating a culture of continuous quality improvement. *Radiographics*. 2022;42:919-928.

46. Flug JA, Stellmaker JA, Tollefson CD, et al. Improving turnaround time in a hospital-based CT division with the kaizen method. *Radiographics*. 2022;42:E125-E131.

47. Sullivan K, Topper L, Rajwani A. Redesigning patient flow in orthopedics and radiology clinics via a three-phase 'Kaizen' improvement approach and interrupted time series analysis. *Int J Qual Health Care*. 2022;34:mzac061.

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