Streamlining and Consistency in Surgery: Lean Six Sigma to Improve Operating Room Efficiency

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Background: Improving perioperative efficiency helps reduce unnecessary surgical expenditure, increase operating room throughput, improve patient safety, and enhance staff and patient satisfaction. Lean Six Sigma (LSS) is a quality improvement model that has been successfully applied to eliminate inefficiencies in the business sector but has not yet been widely adopted in medicine. This study investigates the adaptation of LSS to improve operative efficiency for plastic surgery procedures.

Methods: The authors followed the define, measure, analyze, improve, and control phases to implement LSS. The key outcome measures gathered were operative times, including the cut-to-close time, and the total time the patient spent in the operating room.

Results: The study included a total of 181 patients who underwent immediate bilateral deep inferior epigastric perforator flap breast reconstruction between January of 2016 and December of 2019. The LSS interventions were associated with a decrease in total operative time from 636.36 minutes to 530.35 minutes, and a decrease in the time between incision to closure from 555.16 minutes to 458.85 minutes for a bilateral mastectomy with immediate deep inferior epigastric artery flap breast reconstruction.

Conclusions: This study demonstrates that LSS is useful to improve perioperative efficiency during complex plastic surgery procedures. The workflow of the procedure was improved by determining the optimal spatial positioning and distinct roles for each surgeon and preparing surgeon-specific surgical trays. Two process maps were developed to visualize the positioning of the surgeons during each stage of the procedure and depict the parallel workflow that helped improve intraoperative efficiency. *(Plast. Reconstr. Surg.* 152: 682, 2023.)

Every year, the United States spends close to 18% of its gross domestic product on health care—a value that far surpasses that of any other developed nation.[1] Surgical expenditure accounts for nearly one-third of this national spending.[1] This cost has been projected to increase in coming years, as demand for additional operating rooms and procedural facilities continues to grow.

Improving perioperative productivity and efficiency in the operating room is one approach that may help to reduce unnecessary costs for the hospital and the patient.[1,2] Furthermore, beyond the concrete financial savings, improving operating room efficiency can also increase operating room throughput, improve patient safety, and lead to greater staff and patient satisfaction (Fig. 1).

Historically, quality improvement (QI) or process improvement models such as the Plan-Do-Study-Act model, the Focus-Analyze-Develop-Execute (FADE) model, and the Team Strategies and Tools to Enhance Performance and Patient Safety model have been used to increase productivity and eliminate inefficiencies within health care.[3,4] Alternative QI methodologies that are

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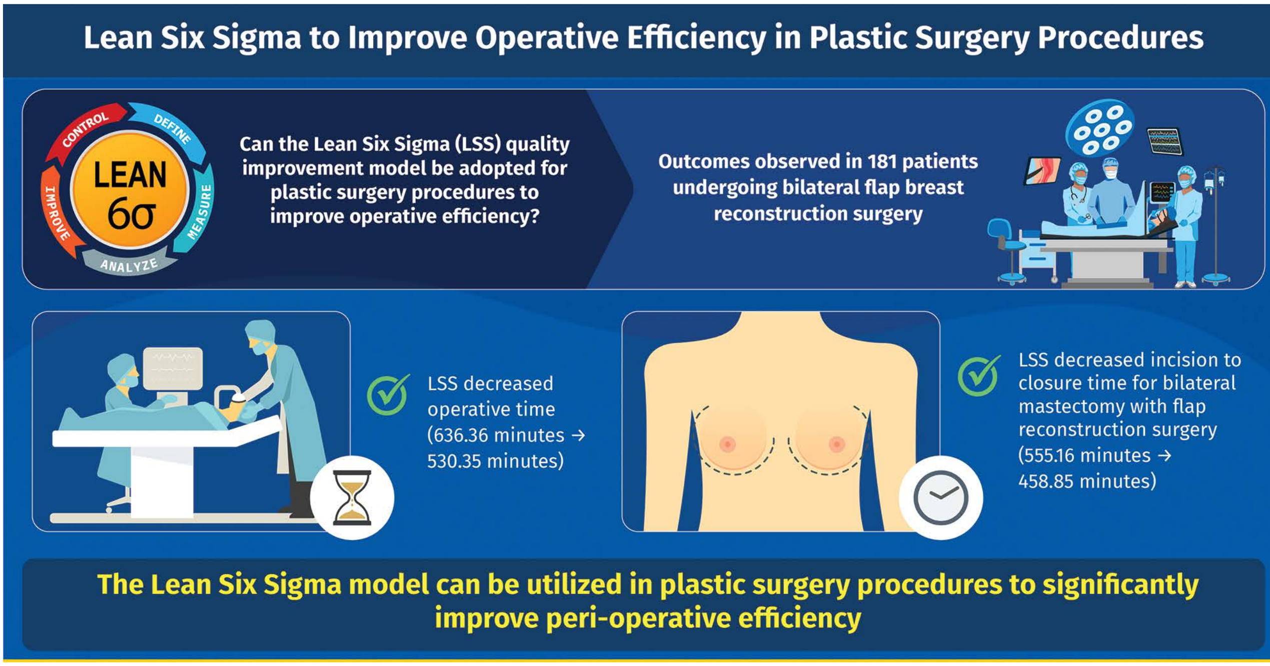

Fig. 1. The Lean Six Sigma model can be used in plastic surgery procedures to significantly improve perioperative efficiency.

regarded as the standard in the business sector, however, have not yet been widely adopted by many groups in medicine. In particular, Lean Six Sigma (LSS) is a QI model that combines two models, Lean and Six Sigma, which were both introduced by prominent leaders in the manufacturing industry and have since been applied in the business, financial services, and government sectors.[5–7]

The Lean methodology evolved from the Toyota production system in the 1990s, a QI initiative led by an engineer and manager at Toyota, Taiichi Ohno.[8–10] Lean is based on a philosophy of continuous improvement that focuses on eliminating different types of "waste" (called *Muda* in Japanese) from a given process. In this context, waste is defined as any action or step that does not provide value to the overall aim of the process. Lean places emphasis on first measuring and analyzing the starting state of the process, after which eight different types of waste are identified: transportation, inventory, motion, waiting, production, overprocessing, defects, and skills (Fig. 2).[8,9] After the areas of waste are identified, a new process is designed to reduce or eliminate them.

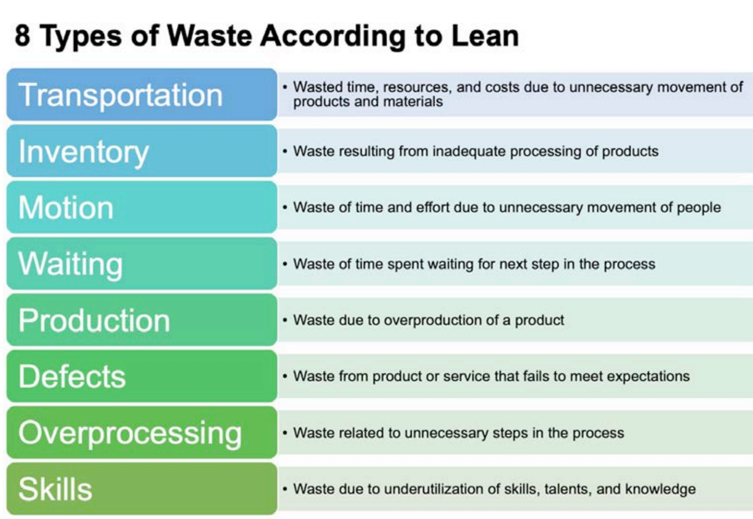

Fig. 2. An explanation of the eight types of waste defined by the Lean QI methodology.

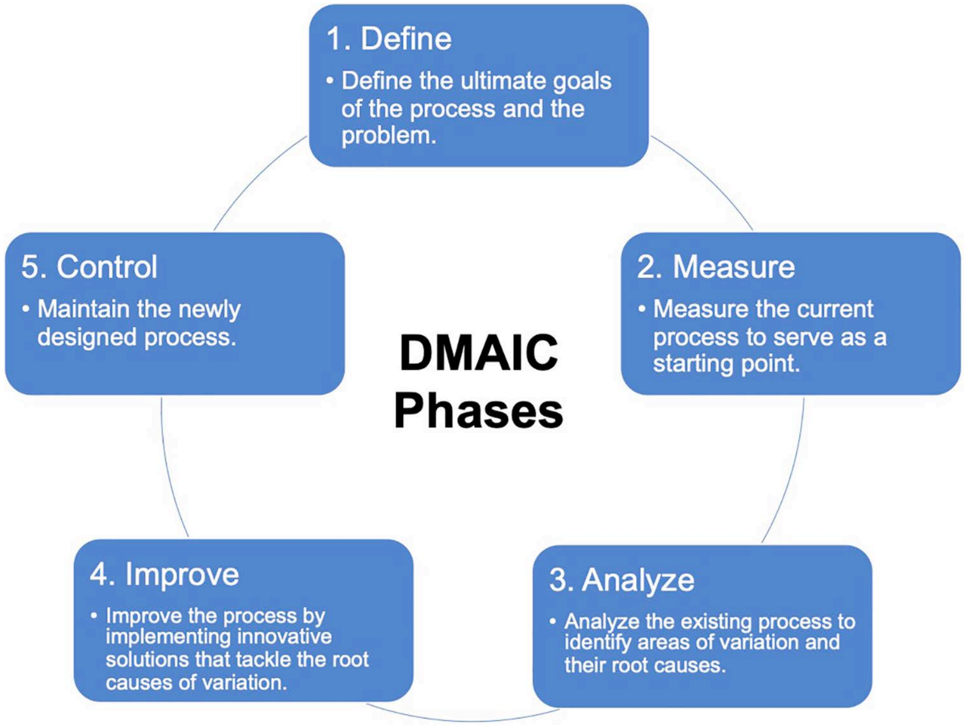

Fig. 3. A visualization of the DMAIC cycle that is used in Six Sigma and LSS.

Similar to Lean, Six Sigma has its roots in the manufacturing industry. The methodology was developed by the Motorola Corporation in 1986 and focuses on eliminating variation and streamlining existing processes to improve efficiency.[8,9] Six Sigma also emphasizes a cycle of continuous improvement and is often implemented in five phases, collectively referred to as the define, measure, analyze, improve, and control (DMAIC) cycle (Fig. 3).[10] The problem being addressed is determined at the define stage. Then, data are gathered during the measure stage to quantify the problem and document a baseline measure. During the analyze stage, the causes of the problems are determined. Steps to eliminate inefficiencies and standardize procedures are implemented and tested at the improve stage, and productive changes are maintained and continuously monitored for areas of further improvement during the control stage (Fig. 3).

The shared emphasis on continuous improvement and approach that involves examining and analyzing an existing process allows Lean and Six Sigma to be easily combined into a single model: LSS. The DMAIC cycle can be used to eliminate both waste and variation in processes, allowing groups to tackle inefficiency by means of a two-prong approach.

Since 2010, some groups have demonstrated success using LSS to improve processes within health care, such as decreasing the length of stay in the hospital for trauma patients or improving glucose control in the cardiac intensive care unit.[9,11–13] However, surgical specialties—in particular, plastic and reconstructive surgery—have been slow to incorporate the LSS methodology to improve processes related to the operating room.[13–15]

The purpose of this study was to investigate whether LSS can be adapted to help improve operative efficiency for plastic surgery procedures. Specifically, we studied the effect of using LSS to optimize the perioperative efficiency of a bilateral mastectomy and simultaneous deep inferior epigastric perforator (DIEP) breast reconstruction operation. The authors believe that this procedure would benefit greatly from waste elimination and standardization because it is a complex, lengthy operation that involves many moving parts.

METHODS

Implementing LSS: The DMAIC Cycle

The authors followed the DMAIC phases to implement LSS. First, during the define stage, a focus group consisting of the operating room personnel most frequently involved in the senior authors' microsurgical DIEP flap breast reconstructions gathered with the two plastic surgeons heading the study to identify the aim of the project: to improve perioperative efficiency of a bilateral mastectomy and simultaneous DIEP flap breast reconstruction operation.

Beginning with the measure stage, the group decided that efficiency would be assessed based on the length of the operation, including both the total in-room patient time and the duration between incision and closure (skin-to-skin time).

In the analyze stage, the group discussed components of the operation that could be standardized or eliminated to improve perioperative efficiency. Given the equipment- and personnel-heavy nature of this procedure, the group focused on determining the optimal position for equipment and people throughout the entire duration of the case. Elements considered included optimal positioning of the Mayo stand, microsurgery microscope, and the back tables. A created process map outlined the overall flow of the operation and defined consistent but distinct surgical procedural. A key component of the LSS paradigm is the "Kanban" method, which encourages the use of visual cues, maps, or posters that workers can easily follow to minimize idle time. Thus, the process map was created to provide both temporal and spatial cues for the entire team in the operating room during the procedure. Finally, specialized instrument trays were created in consultation with the surgeons, and sets were ordered before the day of surgery to minimize instrument-related delays.

The changes were implemented on a specified date during the improve stage and operative times were collected for all subsequent bilateral mastectomy and simultaneous DIEP flap operations. Once it was verified that operative times were improving, the operative team agreed to maintain the changes by remaining consistent with the interventions for all following procedures.

Study Design

The study included all patients who underwent bilateral and immediate DIEP flap breast reconstruction between January 1, 2016, and December 31, 2019, with the two senior plastic surgeon authors at a single academic institution. There were no exclusion criteria. The proposed study activities using recognized QI methodologies were deemed to not be human subjects research by the institution's human research protection program (HSRD21-0399). The LSS changes were implemented at the beginning of January of 2018. Therefore, for data analysis, patients who underwent surgery between January of 2016 and December of 2017 were assigned to the "before-LSS" group, and patients who underwent surgery between January of 2018 and December of 2019 were assigned to the "after-LSS" group. The key outcome measures gathered were operative times, including the cut-to-close time (time between first incision and end of closure) and the total time the patient spent in the operating room (wheels in to wheels out). Operative times of the before-LSS and after-LSS groups were compared by a Welch t test using Python v.3.7. Statistical significance was assigned to a value of $P < 0.05$.

RESULTS

Operational Outcomes

Our study included a total of 181 patients who underwent immediate, bilateral DIEP flap breast reconstruction between January of 2016 and December of 2019. Patients who underwent unilateral or delayed reconstruction and whose operative times were not properly recorded were excluded from the study. Seventy-five patients were included in the before-LSS group and 106 patients were included in the after-LSS group. There were no significant differences in body mass index, age, smoking history, or comorbidities (including diabetes mellitus, dyslipidemia, and hypertension) between patients in the two groups (Table 1).

Total mean operative times, measured as the total time the patient spent in the operating room decreased from 636.36 ± 11.24 minutes to 530.35 ± 6.70 minutes after the LSS interventions occurred (Fig. 4). Similarly, mean cut-to-close time decreased from 555.16 ± 11.48 minutes to 458.85 ± 7.80 minutes (Fig. 5). Both of these decreases in operative time were statistically significant ($P < 0.001$).

Spatial Process Map

Eliminating waste related to motion was a prime focus of our LSS interventions. Figure 6 is the Kanban process map developed to visualize the positioning of the breast surgeon and the two plastic surgeons operating during each stage of the procedure. For simplicity, the two plastic surgeons are referred to as plastic surgeon 1 and plastic surgeon 2 and are represented in red and green, respectively. The focus group also determined that the microscope should always remain in the room and be positioned right behind the first breast that would undergo mastectomy to

Table 1. Patient Demographics and Operative Time Outcomes before and after LSS[a]

	Before LSS	After LSS	*P*
No.	75	106	
Mean cut-to-close time ± SEM, min	555.16 ± 11.48	458.85 ± 7.80	0.001
Mean total time in OR ± SEM, min	636.36 ± 11.24	530.35 ± 6.70	<0.001
Age at the time of surgery, yr	51.55 ± 8.88	52.10 ± 9.32	0.68
BMI, kg/m^2	30.36 ± 6.21	31.12 ± 6.37	0.42
Smoking history	0.29 ± 0.46	0.29 ± 0.46	0.99
Diabetes mellitus	0.066 ± 0.25	0.075 ± 0.27	0.82
Dyslipidemia	0.187 ± 0.39	0.236 ± 0.43	0.42
Hypertension	0.293 ± 0.46	0.274 ± 0.45	0.77

OR, operating room; BMI, body mass index.
[a]Statistical significance was defined as $P < 0.05$. Difference in operative times was the only statistically significant measure.

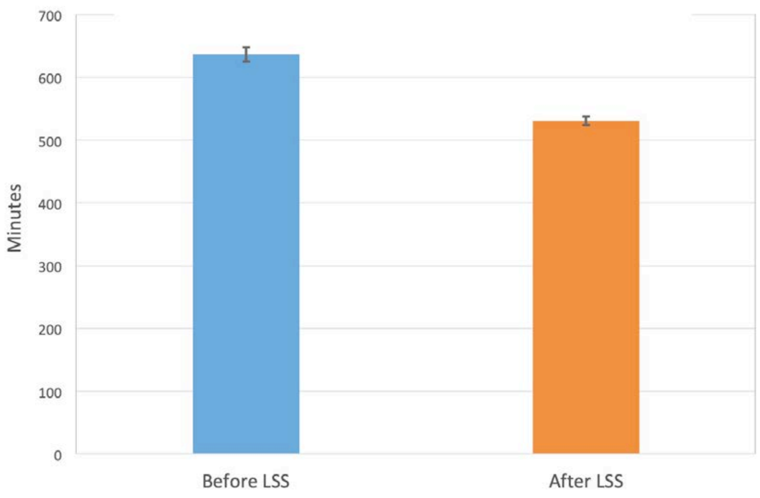

Fig. 4. Bar graph representing total mean operative times before and after LSS interventions. The total time the patient spent in the operating room decreased from 636.36 ± 11.24 minutes to 530.35 ± 6.70 minutes ($P < 0.001$).

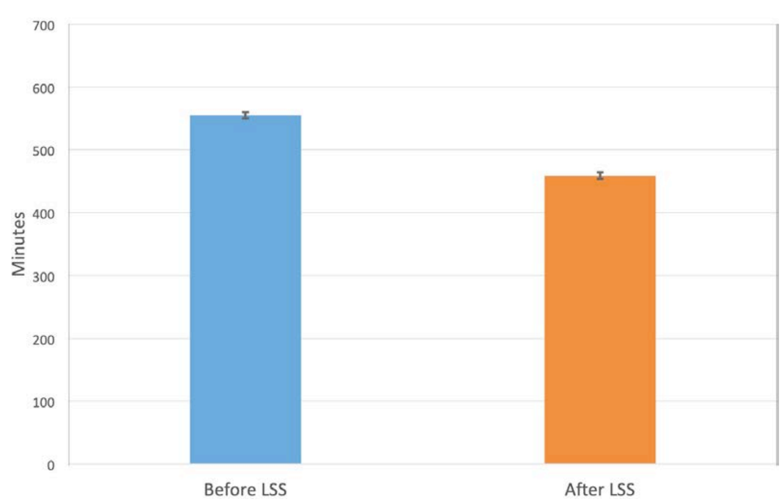

Fig. 5. Bar graph representing mean cut-to-close operative time (duration between incision and closure before and after LSS interventions in minutes) ($P < 0.001$). Cut-to-close time decreased from 555.16 ± 11.48 minutes to 458.85 ± 7.80 minutes ($P < 0.001$).

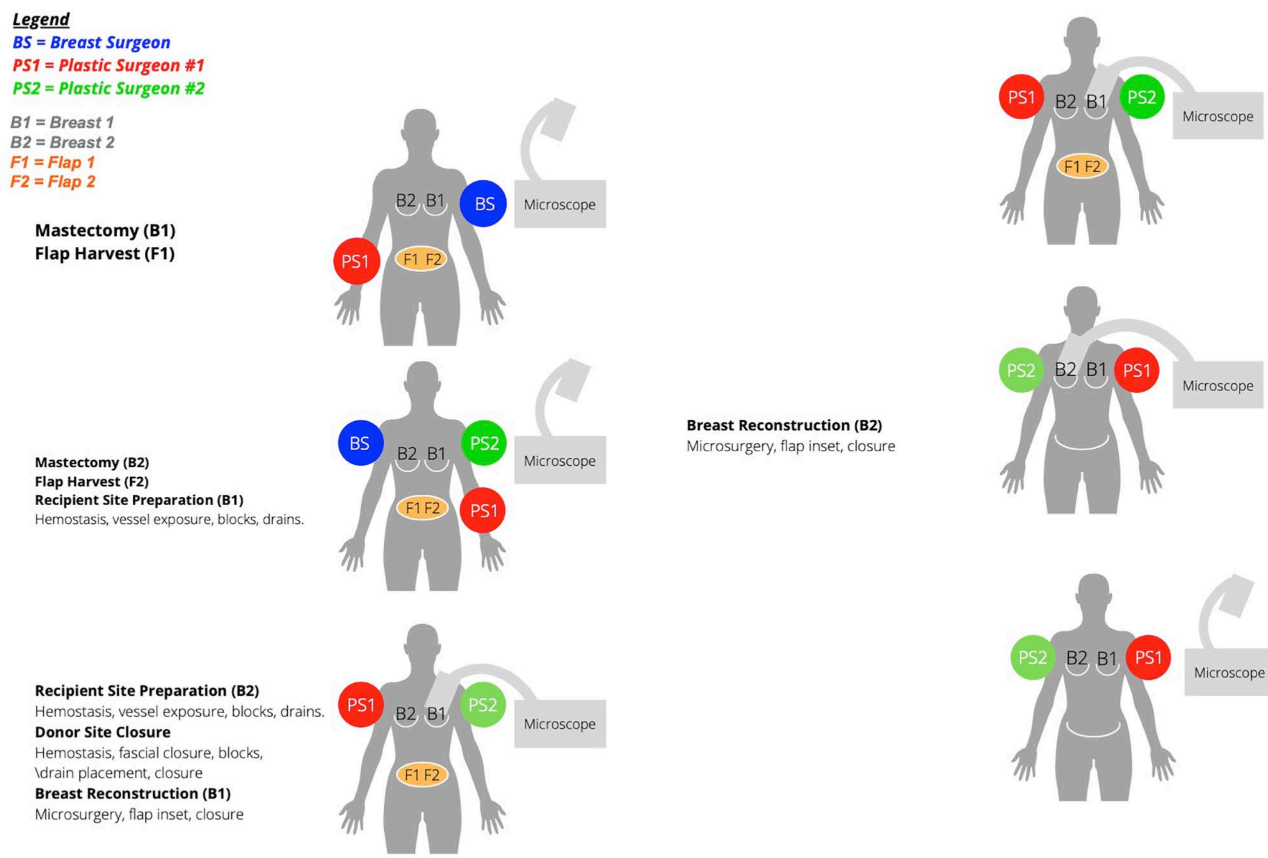

Fig. 6. Spatial process map used to represent physical positioning of each surgeon given the step of the procedure being completed. The breast surgeon is represented in *blue*, the first plastic surgeon in *red*, and the second plastic surgeon in *green*. The location of the microscope is also depicted.

eliminate any delays resulting from attempting to move the large microscope into the room during the case. This detail is included in the process map.

The steps in the spatial process map (Fig. 6) are depicted, as follows:

1. During the first part of the operation, the breast surgeon conducts the mastectomy on the first breast (B1) while plastic surgeon 1 works on harvesting the flap at the contralateral abdominal site.
2. The breast surgeon moves to the other side of the operating table to complete the mastectomy of the second breast (B2). Simultaneously, plastic surgeon 2 begins preparing the recipient vessels at B1, completing hemostasis, exposing the vessels, administering blocks, and preparing any drains. Plastic surgeon 1 works on harvesting the second abdominal flap.
3. With the mastectomy completed, the breast surgeon leaves the room. Plastic surgeon 2 begins microsurgical breast reconstruction and performs flap inset at B1. At the same time, plastic surgeon 1 works on preparing the recipient vessels at B2 and then works on donor-site closure (including hemostasis, fascial closure, and drain placement).
4. Plastic surgeon 1 moves to B1 to assist with closure, while plastic surgeon 2 works on the microsurgical breast reconstruction at B2, followed by flap inset and closure.

A temporal representation of this process map was also created so that each surgeon could easily reference the diagram to see whether they were falling behind schedule relative to the other surgeons in the room (Fig. 7). This temporal process map also depicts the parallel workflow that helped to improve intraoperative efficiency.

DISCUSSION

This study demonstrates that LSS is useful to improve perioperative efficiency during complex procedures in plastic surgery. Our LSS

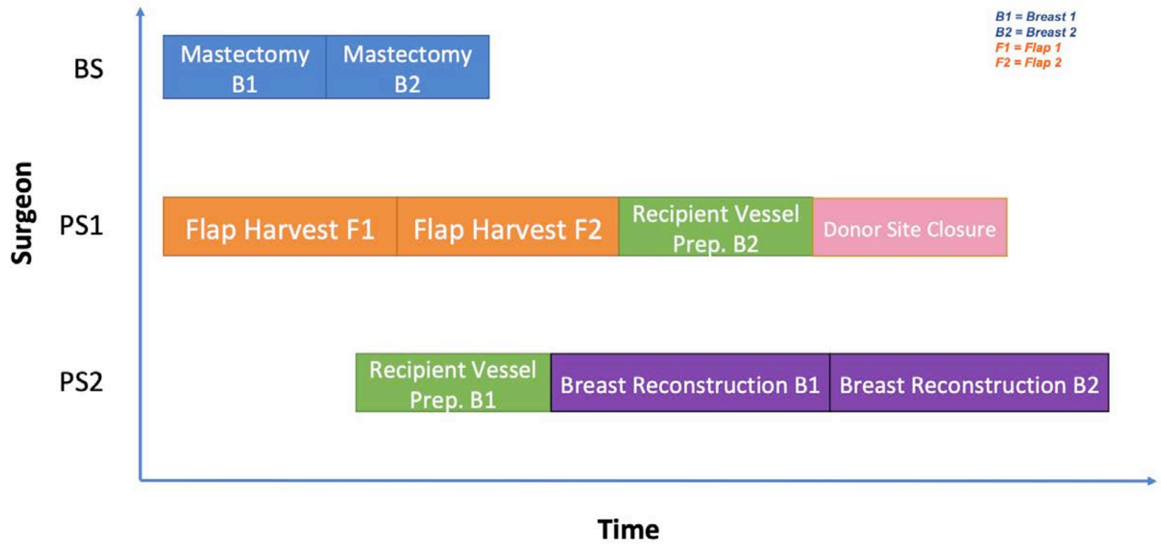

Fig. 7. LSS temporal process map (for bilateral mastectomy and DIEP flap breast reconstruction) used to represent distinct roles for each surgeon and visualize parallel workflow. *BS*, breast surgeon; *PS1*, plastic surgeon 1; *PS2*, plastic surgeon 2.

interventions were associated with a decrease in total operative time from 636 minutes to 530 minutes, and a decrease in the time between incision to closure from 555 minutes to 458 minutes for a bilateral mastectomy with immediate DIEP flap breast reconstruction. Although data related to the financial implications of these decreases in operative times were not collected in this study, it is safe to assume significant cost benefits from shortening an operation's average duration by 1 to 2 hours. Future studies that investigate the financial implications of improving operative efficiency and assess changes in patient and staff satisfaction will help us better quantify the effect of LSS in plastic surgery operations.

It became clear during the define and measure stages of our project that the areas of waste and standardization most relevant for our project were those relating to waiting, motion, and transportation. Determining the optimal spatial positioning of the surgeons themselves served to improve the workflow of the entire operation and allow for multiple tasks, such as flap harvest and mastectomy, to be completed simultaneously (Fig. 8). Moreover, determining distinct and consistent roles for each plastic surgeon helped to improve workflow by preventing them from moving around the operating table unnecessarily. The preparation of surgeon-specific surgical trays minimized delays during the case that resulted from missing instruments, and clear decisions on where to position the major equipment within the operating room saved both space and time.

This study does have limitations. There is a degree of natural improvement in efficiency that is to be expected after a single procedure is repeatedly performed with the same staff at a single institution.[16,17] This natural improvement over time is a potential source of bias in our data. It is difficult to determine what percentage of the decrease in operative time is attributable to increasing familiarity rather than the LSS interventions. However, the dramatic decrease in operative time that is associated with the time of LSS implementation suggests that the changes cannot be fully explained by natural improvements attributable to familiarity. In addition, setting an intentional goal to reduce operative time helped to accelerate team bonding and familiarization with the procedure among operating room staff. Another limitation of our study is that it was not set up to measure the impact of each intervention undertaken. Still, the authors are confident that all of our interventions helped contribute to greater workflow and efficiency, either by introducing uniformity and eliminating waste during the operation or by improving interpersonal dynamics within the operating room.

Finally, because we were implementing a change in surgical procedure that required everyone's involvement, there was no way to blind the study. That is, the surgeons and staff involved knew that the cases were being timed. As stated by the Hawthorne effect, the very awareness of being observed could have caused these individuals to modify their behavior, adding a compounding

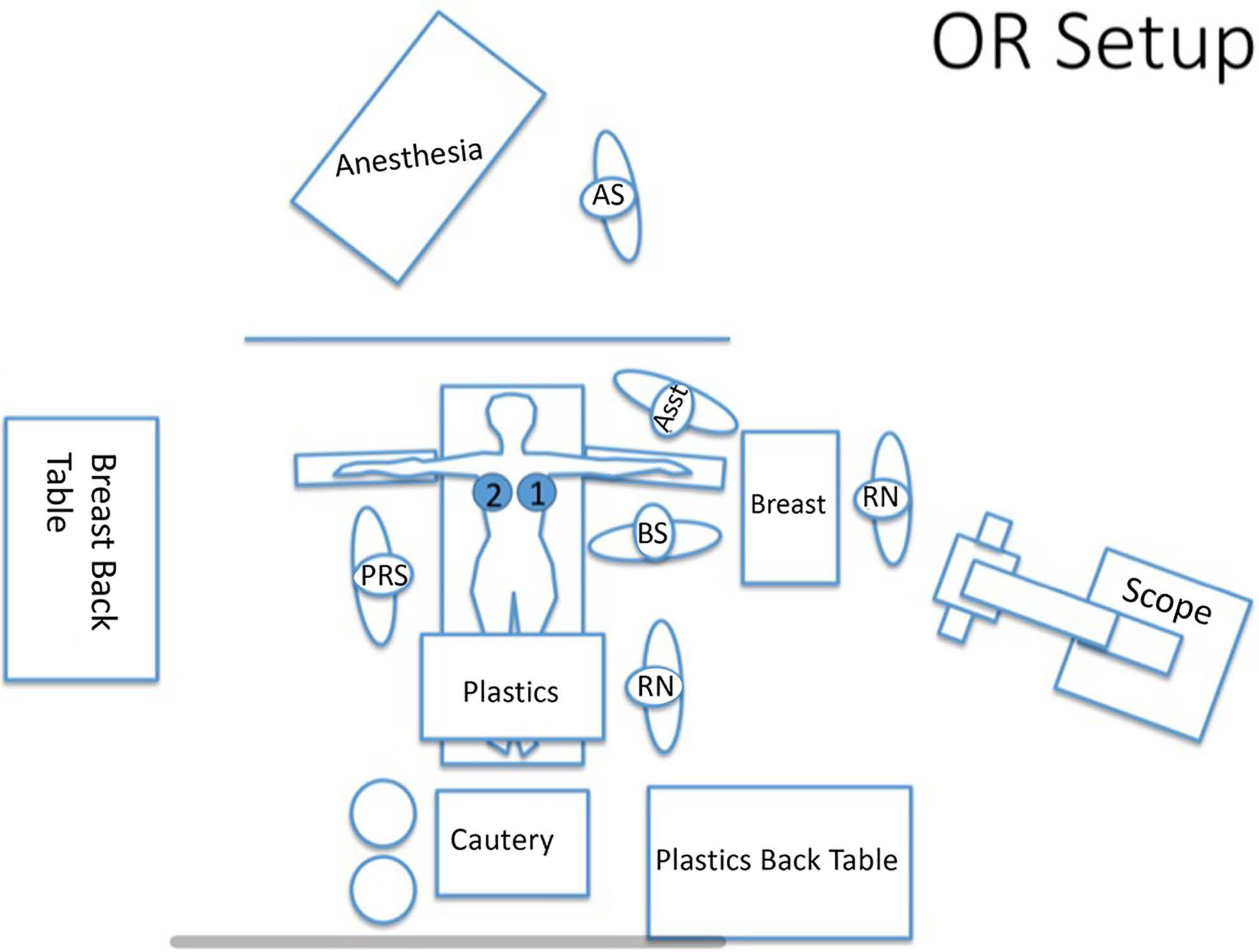

Fig. 8. Determining the optimal spatial positioning of the various surgical teams allowed for improved workflow of the entire operation and multiple tasks. *OR*, operating room; *AS*, anesthetist; *PRS*, plastic and reconstructive surgeon; *BS*, breast surgeon; *Asst*, assitant; *RN*, registered nurse.

variable that influenced results. As with the effect of increasing familiarity, however, the significance of the decrease in operative time after LSS implementation makes it unlikely that the results were entirely attributable to the Hawthorne effect. Future studies should aim to control for this bias by measuring operative times before and after implementing QI methods. In addition, future studies could implement blinded cohorts after implementing LSS by randomly choosing, and not announcing, which procedures will be timed.

Inherent in the idea of LSS is that no process is ever perfect. Although we were able to show improvement in operative times, further interventions or changes in approach could help surgeons obtain an even more efficient way to perform microsurgical breast reconstructions. The purpose of this study is not to present the optimal process flow for all groups conducting a DIEP flap, but simply to encourage each surgeon to reflect on the perioperative efficiencies of their procedures and implement innovative solutions that suit their needs, their staff's needs, and their institution's needs.

Readers should understand that LSS is only one of several QI approaches that can be applied to processes within health care. In addition to just using Lean or just using Six Sigma, many groups have also found success using broader methodologies such as the Plan-Do-Study-Act model, which involves a rapid, trial-and-error approach to test small incremental changes to a process over a short period.[4] The FADE model similarly emphasizes determining a goal and analyzing baseline measures to generate solutions to improve processes. Yet, FADE does not include LSS's framework for waste and standardization that may prove to be too narrow for some situations. Furthermore, for groups looking to improve team performance and patient safety, the Team Strategies and Tools to Enhance Performance and Patient Safety methodology—which focuses on preoperative and postoperative briefings—may be more applicable.[3] No single model is better than the other, and each offers its own advantages.

Surgeons are critical to successful operations improvements in the operating room environment. Success requires that the improvement methodology that best addresses the existing problem be implemented. This study examined the feasibility of applying LSS to improve perioperative efficiency for a specific procedure in plastic surgery. The authors anticipate this example being useful for other surgeons who may consider adding this methodology to their toolkit when considering process improvement projects.

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DISCLOSURE

The authors have no financial interest in any of the products, devices, or drugs mentioned in this article and no financial disclosures to report.

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