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Preparatory Time–Related Hand Surgery Operating Room Inefficiency: A Systems Analysis

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Abstract

Background: No study exists on preparatory time—from patient's entrance into the operating room to skin incision—and its role in hand surgery operating room inefficiency. The purpose of this study was to investigate the length and variability of preparatory time and assess the relationship between several variables and preparatory time. **Methods:** Consecutive upper extremity cases performed for a period of 1 month by hand surgeons were reviewed at 3 surgical sites. Preparatory time was compared across locations. Cases at one location were further analyzed to assess the relationship between preparatory time and several variables. Both traditional statistical methods and Shewhart control charts, a quality control tool, were used for data analysis. **Results:** A total of 288 cases were performed. The mean preparatory times at the 3 sites were 25.1, 25.7, and 20.7 minutes, respectivley. Aggregated preparatory time averaged 24.4 (range 7-61) minutes, was 75% the length of the surgical time, and accounted for 34% of total operating room time. Control charts confirmed substantial variability at all locations, signifying a poorly defined process. At a single site, where 189 cases were performed by 14 different surgeons, there was no difference in preparatory time by case type, American Society of Anesthesiologists status, or case start time. Preparatory time varied by surgeon and anesthesia type. **Conclusions:** Preparatory time was found to be a source of inefficiency, independent of the surgical site. Control charts reinforced large variations, signifying a poorly designed process. Surgeon seemingly plays an important, albeit likely indirect, role. Efforts to improve operating room workflow should include preparatory time.

Keywords: operating room, efficiency, workflow, control charts, hand surgery

Introduction

Operating room efficiency is a matter of high priority for hospitals and surgeons alike. For this reason, numerous studies have been published in various surgical fields with the goals of identifying modifiable sources of inefficie ncy.[1-23] Most of this literature has focused on either overall operative workflow or turnover time as end points. Turnover time has traditionally been the focus of scrutiny as it is neither financially nor clinically beneficial to the hospital or the patient.[24] Hand surgery, a high-volume specialty with many procedures and short operative duration, is particularly susceptible to the deleterious effects of delays that may occur outside the surgical time.

Thus, it is no surprise that the limited hand surgery data on operating room efficiency have focused on turnover time: Gottshalk et al[25] recently identified turnover time to be influenced by several factors, including surgeon routine, surgery location (main hospital vs ambulatory center), the patient's American Society of Anesthesiologists (ASA) class, procedure type, and case order. Avery et al[26] also found that a dedicated orthopedic-specific staff can reduce turnover time in hand surgery. Beyond the realm of hand surgery, studies have suggested that overall nonsurgical time—from the end of a surgery to the start of the following surgery—is a better target for increasing operating room efficiency. Within upper extremity surgery, similar assessments have focused on the effects of different anesthesia types on nonsurgical time, finding that local anesthesia or regional blocks reduced nonsurgical time by 7 to 16 minutes.[26,27] However, no study, in hand surgery or any other

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surgical field, has analyzed preparatory time—a part of nonsurgical time defined as the time from entry of the patient into the operating room to the time of incision—as a source of operating room inefficiency.

Shewhart control charts, named after Dr Walter A. Shewhart of Bell Telephone Laboratories, are a statistical process control tool used in many industries,[28] and to a lesser extent in health care, for statistical quality control. As a robust graphical statistical tool, control charts are used in a variety of industries to identify modifiable variations in a process. Within health care, control charts have been implemented in quality improvement in a variety of fields,[29-35] ranging from military injuries to transplant lists to neonatal care. Control charts determine whether a process is in control—minimum nonrandom or "assignable" variation with predictable variation. Processes with assignable variation are undesirable and inefficient. These out-of-control processes can, and should, be investigated to improve on the process.[36] Once a process is in control, it is important to continually improve to decrease the degree of normal and predictable variation.

The purpose of this study was, therefore, to use both traditional statistical methods and Shewhart control charts (a statistical control method) to: (1) investigate the length and variability of preparatory time at different surgical sites; and (2) assess the relationship between several variables and preparatory time.

Materials and Methods

1. All consecutive upper extremity cases performed in 1 calendar month by board-certified hand surgeons were reviewed at 3 surgical sites: an orthopedic-only hospital, a university-based outpatient surgery center, and a private surgery center. Shoulder procedures were neither included nor were "wide-awake" procedures performed under local anesthesia only. The primary end point assessed was preparatory time, defined as the time from the entry of the patient into the operating room to the time of skin incision, and this time was compared across the 3 surgical sites. Data were also collected on surgical time—from incision to closure—to compare it with preparatory time.
2. All cases performed at the university-based outpatient surgery center were further analyzed to assess the relationship between preparatory time and several variables. For each case at this location, additional categorical data were recorded, including case type, surgeon, ASA status, case start time, and whether a regional nerve block was performed by anesthesiologists in the operating room. Case start time was categorized as "first start," "early," or "late," with "early" cases being defined as those with a patient entry before 2 PM and late after 2 PM. First-start cases were included in the early cases. Nerve blocks were either supraclavicular or infraclavicular.

To analyze the data, both traditional statistical methods and Shewhart control charts were used. For the traditional statistics, which included *t* tests and analyses of variance (ANOVAs), Stata Statistical Software: Release 11 (StataCorp LP, College Station, Texas) was used. ProAptive Metrics Analysis Software 2.0 (APT Leadership, LLC, Great Brak River, South Africa) was used to generate 3-sigma square root–transformed Shewhart control charts.

The control chart graph plots data points sequentially across the x-axis in time sequence and has 3 main components: a center line or average of the process, an upper control limit, and a lower control limit. Although control limits can vary, 3-sigma (standard deviations) from the process mean is most commonly used. Assignable variation is identified by the presence of points plotted beyond the upper and lower control limits. This variation is statistically greater than that which can be accounted for by common cause variation.[37] The presence of multiple points outside the control limits is the basic criterion to identify a process that is out of control. A sequence of 8 consecutive points on the same side of the center line is one criterion used to identify a "shift" or a change in the performance of the process.[38] The presence of assignable variation designates events where variability is not from the system but from an external cause and should be further investigated to improve on the process. When the process is improved, assignable variation is eliminated, and the process is deemed to be in control. However, this shows that the process is well defined. If control charts reveal substantial variability within limit variation, then that signifies a poorly defined process—one that would need major overhaul or redefinition to improve its reproducibility and efficiency.

Results

A total of 288 cases were performed: 39 at the orthopedic hospital, 189 at the university-based outpatient surgery center, and 60 at the private surgery center. Mean preparatory time ranged from 20.7 minutes at the private surgery center to 25.5 minutes at the university-based outpatient surgery center ($P < .0005$). Aggregating the data, mean preparatory time was 24.4 ± 8.5 minutes, represented 75% of the length of surgical time (from incision to closure), and accounted for 34% of the total operating room time (Table 1). Control charts revealed high "within-limit" variability at all locations, as well as assignable causes of variation, that is, outliers defined as special-cause events,

Table 1. Hand Surgery Preparatory Time at Different Surgery Sites.

Location	N	Mean, min	Range, min	Relative to surgical time,[a] %	Portion of total case time,[b] %
University-based orthopedic-only hospital	39	25.1 ± 8.1	7-46	51	26
University-based outpatient surgery center	189	25.5 ± 9.4	7-61	82	36
Private surgery center	60	20.7 ± 8.3	8-36	65	34
All	288	24.4 ± 8.5	7-61	75	34
		$P < .0005$[c]			

[a]Surgical time is defined as time from skin incision to closure.
[b]Case time is defined as time from patient entering to leaving the operating room.
[c]Analysis of variance testing.

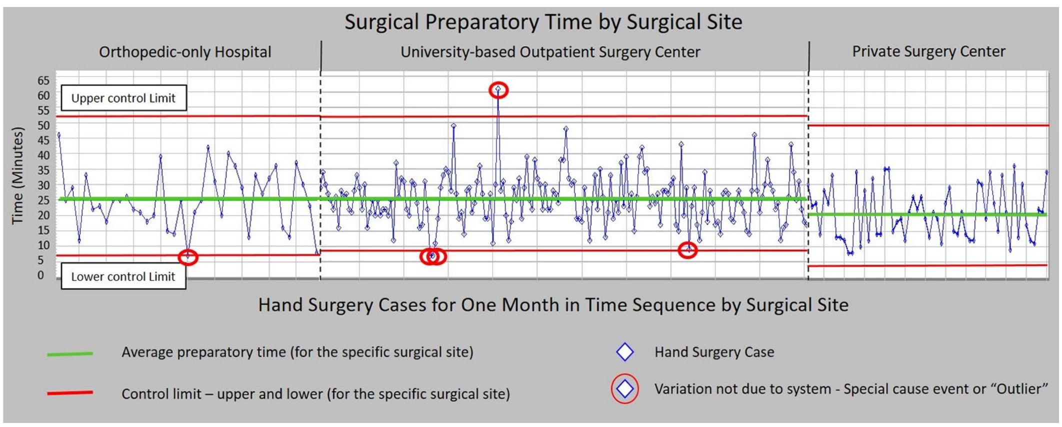

Figure 1. Preparatory time control chart at all surgical sites.
Control chart with 3-sigma square root transformation. Red lines represent upper and lower control limits. "O" denotes 5 outliers. Upper control limits at 3 sites (left to right): 52.0, 51.7, and 39.5 minutes. Lower control limits (left to right): 6.9, 8.0, and 4.8 minutes.

at both the orthopedic-only hospital and university-based outpatient surgery center (Figure 1).

At the university-based outpatient surgery center, 189 procedures were performed by 14 different hand surgeons. Mass excision was the most commonly performed procedure, accounting for 31 of the 189 cases. Carpal tunnel release was the second most frequent procedure, with 24 median nerve decompressions occurring at the wrist. There was no difference in preparatory time by case type (P = .22) (Table 2). There was also no difference in preparatory time by ASA status (P = .85), for early versus late cases (P = .59) nor for first-start procedures (P = .13) (Table 3). A regional block performed by an anesthesiologist in the operating room was associated with an average of 6.2 additional minutes of preparatory time ($P < .0001$). There was also difference in preparatory time by surgeon ($P < .0001$), ranging from a mean of 17 ± 5.2 minutes for surgeon 10 to 32.7 ± 10.4 minutes for surgeon 3. Three surgeons had a mean preparatory time greater than 30 minutes, 6 between 25 and 30 minutes, 4 between 20 and 25 minutes, and 1 less than 20 minutes. A summary of this site's preparatory time by ASA status, case time, the presence of a nerve block, and surgeon is detailed in Table 3.

This site's control chart for preparatory time by block status demonstrated that the process was out of control (ie, has outliers or "special causes") when an anesthesia block was performed and within control limits when no block was performed (Figure 2). The control chart for preparatory time by surgeon further exposed a process shift assignable to the surgeon, with surgeon 14 generating 13 (consecutive) data points below the process average (Figure 3).

Discussion

Maximizing efficiency is an important component of operating room workflow, which has been the focus of many studies.[1,2,4-12,14-22,24,27] In hand surgery, a field with high case volume, opportunities to decrease the time spent between cases have been the focus of the relatively limited existing literature.[25,26] However, most of these have focused on turnover time, and little attention has been paid to preparatory time. It was therefore the purpose of this study to assess,

Table 2. Preparatory Time by Case Performed at University-Based Outpatient Surgery Center.

Case type	N	Preparatory time, min	P value[a]
Mass excision	31	23.3 ± 6.0	.22
Carpal tunnel release	24	25.0 ± 6.7	
ORIF distal radius	18	24.8 ± 6.2	
ORIF finger or hand	16	25.9 ± 10.6	
Trigger finger release	15	24.5 ± 5.9	
Tendon NOS	13	23.8 ± 9.4	
Removal of hardware	10	25.5 ± 7.8	
Wrist arthroscopy	8	29.4 ± 10.0	
Nerve decompression	7	21.9 ± 7.5	
Closed reduction percutaneous pinning	6	28.7 ± 2.4	
Other	41	28.3 ± 9.8	
Total	189	25.5 ± 8.1	

Note. ORIF = open reduction internal fixation; NOS = not otherwise specified (includes repairs, transfers, and non-trigger finger releases).
[a]*P* value derived from analysis of variance testing.

Table 3. Preparatory Time by Study Variables at University-Based Outpatient Surgery Center.

Variable	N	Preparatory time	P value[a]
American Society of Anesthesiologists status	164		.85
1	71	25.6 ± 8.6	
2	88	25.6 ± 7.7	
3	5	27.8 ± 11.1	
Early case			.59
Yes	160	25.5 ± 8.3	
No	29	23.9 ± 8.6	
First start[b]			.13
Yes	49	24.0 ± 8.6	
No	140	26.0 ± 7.9	
Nerve block[c]			<.0001[a]
Yes	92	28.7 ± 7.8	
No	97	22.5 ± 7.2	
Surgeon			<.0001[a]
1	3	27.0 ± 6.1	
2	3	31.0 ± 10.4	
3	13	32.7 ± 10.4	
4	6	28.3 ± 8.3	
5	11	24.0 ± 8.4	
6	14	25.9 ± 6.6	
7	21	30.4 ± 5.8	
8	7	27.0 ± 5.7	
9	29	25.9 ± 7.2	
10	5	17.2 ± 5.7	
11	16	26.7 ± 7.0	
12	29	20.9 ± 9.1	
13	17	23.5 ± 5.4	
14	15	21.5 ± 5.9	

[a]*P* values derived from analysis of variance or *t* tests depending on the number of variables compared.
[b]Early versus late defined as case start time before or after 2 PM.
[c]Peripheral nerve block performed by anesthesiologist in the operating room.

with both traditional statistical methods and Shewhart control charts, variations in preparatory time as a potentially overlooked source of operating room inefficiency.

This study has limitations. First, this study assesses the preparatory time at only 3 sites, thus limiting the generalizability of the results. To our knowledge, only one other study of Caggiano et al[39] reports preparatory time for hand surgery cases, and although the mean preparatory time in that study was shorter (12.5 minutes for procedures performed under monitored anesthesia care [MAC]), the range was wide (3-30 minutes), which is consistent with our finding of high variability. Moreover, Caggiano et al had extensive exclusion criteria in an effort to standardize processes. The second limitation of this study is the heterogeneity of the reported cases, which included soft tissue and bony cases from fingertip to elbow, as well as arthroscopic, open, and percutaneous procedures. Arthroscopic procedures, for example, which require tower setup, had an average preparatory time of 29.4 minutes. However, ANOVA testing revealed no differences in preparatory times by case. Third, because different surgeons had different case volumes at the study's surgical center, there is a wide range of cases (from 3 to 29) for each surgeon. Future studies could expand the time period assessed to obtain even numbers across surgeons; however, this would potentially introduce time-related confounders into the study.

Despite these limitations, this study highlights an undesirable inefficiency in the hand surgery preparatory process, which has not been the focus of previous literature. Preparatory time was 75% the length of surgical time and averaged more than 24 minutes. More important, however, is the substantial variability in preparatory time, which ranged from 7 to 61 minutes and was not related to the type of procedure performed. Control charts confirmed that the preparatory process is "out of control" at 2 of the sites (Figure 1), with several outliers beyond upper and lower control limits. This assignable variability is more than could be explained by natural variation and emphasizes the need to seek out its causes to improve on the process.[37] There was also substantial within-limit variation at all sites, including the private surgery center. Although the mean preparatory time was lower at this location, it still remained high at 21 minutes and highly variable (ranging from 8 to 36 minutes).

It is very important to note that in this study, most of the preparatory times fall within the control limits. The take-away point is that this variability (within the control limits) reveals a predictable system, albeit predictably, variable. This large variability, even though within the control limits,

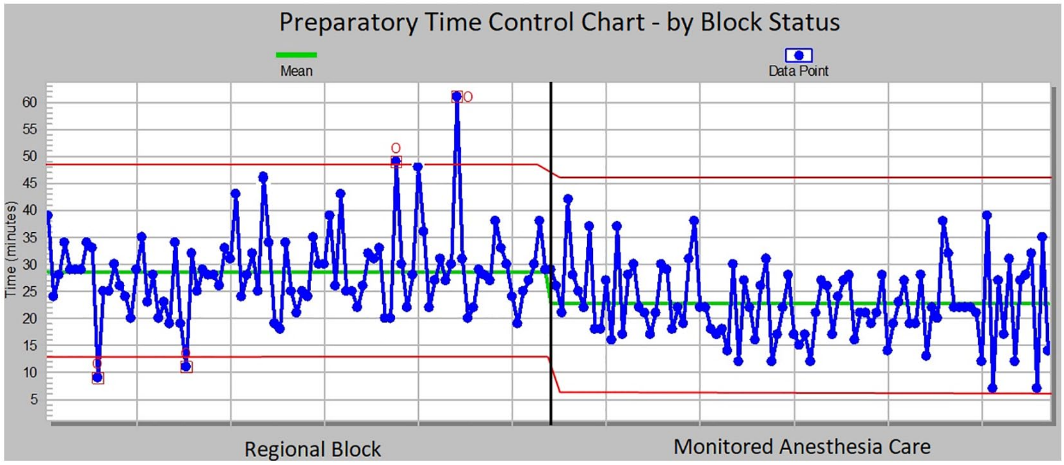

Figure 2. Preparatory time control chart—by block status.
Control chart with 3-sigma square root transformation. Red lines represent upper and lower control limits. "O" denotes 5 outliers. Black line divides cases by block (left of line) or no block (right of line). For cases with regional block performed by an anesthesiologist (N = 97), mean preparatory time was 28.7 minutes; upper control limit, 48.7 minutes; and lower control limit, 13.1 minutes. For cases without block (monitored anesthesia care), mean preparatory time was 22.5 minutes; upper control limit, 46.0 minutes; and lower control limit, 7.0 minutes.

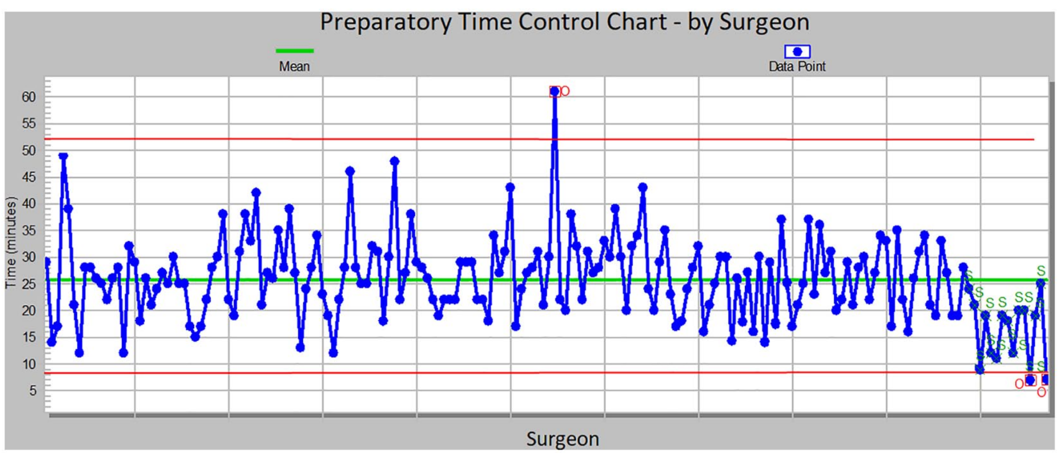

Figure 3. Preparatory time control chart—by surgeon.
Control chart with 3-sigma square root transformation. Red lines represent upper and lower control limits. Surgeon "S" (right of graph) denotes surgeon 14 with all cases below center line (mean = 25.5 minutes). "O" denotes 4 outliers. Upper control limit was 51.7 minutes and lower control limit 8.0 minutes.

is not desirable. When variability is high but falls within the control limits, it is a signal that the process needs to be improved or redesigned. This is very different when there is attributable variability (special cause) where those specific causes need to be investigated and removed if undesirable or implemented globally if desirable. The large variability in our data reveals that the process for patient preparation in the operating room is either poorly implemented or may not even exist. A well-designed system for patient preparation in the operating room would include a specific process flow that identifies tasks, sequence of tasks, and member(s) of team to perform the task for each point once the patient enters the operating room with minimal delay between tasks. A well-designed process flow would be able to answer the following questions: who places the patient on the operating table, who then removes the bed and places it in the hallway, at what point is the tourniquet placed and by whom, and so on. If the process is well implemented, the variability of the system (points between the control limits) would be much less.

The amount of variability found in this study is consistent with the aforementioned work of Caggiano et al.[39] Although the work by Caggiano et al focused on the effects of different anesthesia types on total nonsurgical time, which includes postsurgical time, turnover time, and preparatory time, they did report the ranges for their preparatory times. These ranges were 2 to 33 minutes for cases performed under general anesthesia, 3 to 30 minutes for MAC/local anesthesia, and, perhaps most strikingly, 1 to 26 minutes for cases performed under local anesthesia only. Moreover, the work by Caggiano et al only included cases that required a hand pack and up to 2 standard trays, excluding procedures that required fluoroscopy, drills, implants, microscopes, special positioning, or special equipment. With so many variables eliminated, it is surprising that the authors of this study did not comment on why the variability of their preparatory process was also so large.

In our study, we could not associate variations in preparatory time with case type, ASA status, or case start time, which have all been shown to be related to turnover time in hand surgery.[25] In addition, a regional anesthesia block performed in the operating room added only an average of 6 minutes to the preparatory process. Anecdotally, blocks certainly seem to take more than 6 minutes, and we hypothesize that this time is absorbed by other variations in the preparatory process. Interestingly, the control chart for cases with blocks demonstrated multiple outliers (Figure 2)—both above and below control limits—whereas those without blocks did not contain any, thereby suggesting that the preparatory process may be destabilized by the additional task of preoperative nerve block. One hypothesis for this finding is that resources, that is, staff attention, are drawn from other duties to assist with the block; however, this would not explain outliers below control limits.

An assessment of preparatory time by surgeon with both ANOVA testing and control charts suggests that the surgeon plays an important role in the preparatory process. Surgeon 3, for example, averaged nearly 33 minutes of preparatory time, versus surgeon 10 who averaged just over 17 minutes (Table 3). Control charts (Figure 3) demonstrated that the preparatory time of surgeon 14 was consistently below the process average, and thereby identifies an assignable cause of variation, otherwise known as a “shift” in the process. This particular surgeon often spends his time between cases in the operating room, but not performing staff-assigned duties. We hypothesize that the shift is therefore most likely due to the surgeon either knowingly or unknowingly implementing a more efficient process and/or behavioral changes, that is, motivation influenced by the presence of surgeon. This does not necessarily advocate for a persistent presence of surgeon in the operating room, which has opportunity costs of its own. It does, however, emphasize that the process has potential for significant improvement.

In summary, although much attention is paid to improving operating room efficiency, this study is the first to specifically assess preparatory time. The findings reveal that the preparatory process is a highly variable, and thus an undesirable, but potentially modifiable source of operating room inefficiency. Surgeon seemingly plays an indirect but important role, and the addition of a preoperative nerve block further destabilizes the process. Any attempt to improve workflow should not overlook the preparatory process. Control chart analyses can be implemented to direct process improvement by identifying assignable causes of variation versus variation arising from the process itself.

Ethical Approval

Institutional review board approval was not required for this study as no identifiable private information was collected.

Statement of Human and Animal Rights

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008.

Statement of Informed Consent

This article does not contain any studies with animal subjects.

Declaration of Conflicting Interests

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References

1. Pedron S, Winter V, Oppel EM, et al. Operating room efficiency before and after entrance in a benchmarking program for surgical process data. *J Med Syst*. 2017;41(10):151.
2. Tagge EP, Thirumoorthi AS, Lenart J, et al. Improving operating room efficiency in academic children’s hospital using Lean Six Sigma methodology. *J Pediatr Surg*. 2017;52(6):1040-1044.
3. Souders CP, Catchpole KR, Wood LN, et al. Reducing operating room turnover time for robotic surgery using a motor racing pit stop model. *World J Surg*. 2017;41(8):1943-1949.
4. Padegimas EM, Hendy BA, Lawrence C, et al. An analysis of surgical and nonsurgical operating room times in high-volume shoulder arthroplasty. *J Shoulder Elbow Surg*. 2017;26(6):1058-1063.

5. van Veen-Berkx E, van Dijk MV, Cornelisse DC, et al. Scheduling anesthesia time reduces case cancellations and improves operating room workflow in a university hospital setting. *J Am Coll Surg*. 2016;223(2):343-351.
6. Pimentel MT, Flanagan H, Philip BK, et al. Qualitative analysis of barriers to efficient operating room turnovers in a tertiary care academic medical center. *J Med Pract Manage*. 2015;30(6 Spec No):30-35.
7. Weld LR, Stringer MT, Ebertowski JS, et al. TeamSTEPPS improves operating room efficiency and patient safety. *Am J Med Qual*. 2016;31(5):408-414.
8. Bhatt AS, Carlson GW, Deckers PJ. Improving operating room turnover time: a systems based approach. *J Med Syst*. 2014;38(12):148.
9. Wu ZF, Jian GS, Lee MS, et al. An analysis of anesthesia-controlled operating room time after propofol-based total intravenous anesthesia compared with desflurane anesthesia in ophthalmic surgery: a retrospective study. *Anesth Analg*. 2014;119(6):1393-1406.
10. Austin TM, Lam HV, Shin NS, et al. Elective change of surgeon during the OR day has an operationally negligible impact on turnover time. *J Clin Anesth*. 2014;26(5):343-349.
11. van Veen-Berkx E, Bitter J, Elkhuizen SG, et al. The influence of anesthesia-controlled time on operating room scheduling in Dutch university medical centres. *Can J Anaesth*. 2014;61(6):524-532.
12. Kodali BS, Kim KD, Flanagan H, et al. Variability of subspecialty-specific anesthesia-controlled times at two academic institutions. *J Med Syst*. 2014;38(2):11.
13. Kodali BS, Kim D, Bleday R, et al. Successful strategies for the reduction of operating room turnover times in a tertiary care academic medical center. *J Surg Res*. 2014;187(2):403-411.
14. Small TJ, Gad BV, Klika AK, et al. Dedicated orthopedic operating room unit improves operating room efficiency. *J Arthroplasty*. 2013;28(7):1066-1071.e2.
15. Stepaniak PS, Vrijland WW, de Quelerij M, et al. Working with a fixed operating room team on consecutive similar cases and the effect on case duration and turnover time. *Arch Surg*. 2010;145(12):1165-1170.
16. van Det MJ, Meijerink WJ, Hoff C, et al. Interoperative efficiency in minimally invasive surgery suites. *Surg Endosc*. 2009;23(10):2332-2337.
17. Eappen S, Flanagan H, Lithman R, et al. The addition of a regional block team to the orthopedic operating rooms does not improve anesthesia-controlled times and turnover time in the setting of long turnover times. *J Clin Anesth*. 2007;19(2):85-91.
18. Harders M, Malangoni MA, Weight S, et al. Improving operating room efficiency through process redesign. *Surgery*. 2006;140(4):509-514; discussion 514-516.
19. Friedman DM, Sokal SM, Chang Y, et al. Increasing operating room efficiency through parallel processing. *Ann Surg*. 2006;243(1):10-14.
20. Sokolovic E, Biro P, Wyss P, et al. Impact of the reduction of anaesthesia turnover time on operating room efficiency. *Eur J Anaesthesiol*. 2002;19(8):560-563.
21. Williams BA, Kentor ML, Williams JP, et al. Process analysis in outpatient knee surgery: effects of regional and general anesthesia on anesthesia-controlled time. *Anesthesiology*. 2000;93(2):529-538.
22. Dexter F. Application of prediction levels to OR scheduling. *AORN J*. 1996;63(3):607-615.
23. Mazzei WJ. Operating room start times and turnover times in a university hospital. *J Clin Anesth*. 1994;6(5):405-408.
24. Dexter F, Traub RD. How to schedule elective surgical cases into specific operating rooms to maximize the efficiency of use of operating room time. *Anesth Analg*. 2002;94(4):933-942.
25. Gottschalk MB, Hinds RM, Muppavarapu RC, et al. Factors affecting hand surgeon operating room turnover time. *Hand (N Y)*. 2016;11(4):489-494.
26. Avery DM III, Matullo KS. The efficiency of a dedicated staff on operating room turnover time in hand surgery. *J Hand Surg Am*. 2014;39(1):108-110.
27. Mariano ER, Chu LF, Peinado CR, et al. Anesthesia-controlled time and turnover time for ambulatory upper extremity surgery performed with regional versus general anesthesia. *J Clin Anesth*. 2009;21(4):253-257.
28. Shewhart W. *Economic Control of Quality of the Manufactured Product*. New York, NY: Van Nostrand; 1931.
29. Schuh A, Canham-Chervak M, Jones BH. Statistical process control charts for monitoring military injuries. *Inj Prev*. 2017;23(6):416-422.
30. Wiemken TL, Furmanek SP, Carrico RM, et al. Process control charts in infection prevention: make it simple to make it happen. *Am J Infect Control*. 2017;45(3):216-221.
31. Boudreaux-Kelly M, Wilson M, Bokhari M. Statistical methods of risk-adjusted statistical process control charts to assess surgical performance in consecutive colorectal operations at a single institution. *JAMA Surg*. 2015;150(3):271-272.
32. Varona MA, Soriano A, Aguirre-Jaime A, et al. Statistical quality control charts for liver transplant process indicators: evaluation of a single-center experience. *Transplant Proc*. 2012;44(6):1517-1522.
33. Lawson EH, Hall BL, Esnaola NF, et al. Identifying worsening surgical site infection performance: control charts versus risk-adjusted rate outlier status. *Am J Med Qual*. 2012;27(5):391-397.
34. Lighter DE, Tylkowski CM. Case study: using control charts to track physician productivity. *Physician Exec*. 2004;30(5):53-57.
35. Laffel G, Luttman R, Zimmerman S. Using control charts to analyze serial patient-related data. *Qual Manag Health Care*. 1994;3(1):70-77.
36. Noyez L. Control charts, Cusum techniques and funnel plots. A review of methods for monitoring performance in healthcare. *Interact Cardiovasc Thorac Surg*. 2009;9(3):494-499.
37. Russo SL, Camargo ME, Fabris JP. Applications of control charts ARIMA for autocorrelated data. In: Fallah Nezhad MS, ed. *Practical Concepts of Quality Control*. London, England: InTech Open Access; 2012:31-53.
38. Montgomery D. *Introduction to Statistical Quality Control*. Vol. 1. 6th ed. Hoboken, NJ: John Wiley & Sons; 2009.
39. Caggiano NM, Avery DM, Matullo KS. The effect of anesthesia type on nonsurgical operating room time. *J Hand Surg Am*. 2015;40(6):1202-1209.e1.