Research review

Efficiency improvement in the operating room

Abigail J. Fong, MBA,a,b Meghan Smith, MBA,a,c and Alexander Langerman, MD, SMa,c,*

a University of Chicago Operative Performance Research Institute, Chicago, Illinois
b Pritzker School of Medicine, University of Chicago, Chicago, Illinois
c Department of Surgery, Section of Otolaryngology—Head and Neck Surgery, University of Chicago, Chicago, Illinois

Article info

Article history:
Received 23 August 2015
Received in revised form 15 March 2016
Accepted 20 April 2016
Available online 29 April 2016

Keywords:
Efficiency
Operating room
Surgery
Intraoperative
Lean
Six sigma
Total quality improvement
Process mapping

Abstract

Background: In the changing health care environment, health systems, hospitals, and health care providers must focus on improving efficiency to meet an increasing demand for high-quality, low-cost health care. Much has been written about strategies and efforts to improve efficiency in the perioperative periods, yet the time when the patient is in the operating room— the intraoperative period— has received less attention. Yet, this is the period in which surgeons may have the most influence.

Methods: Systematically review published efforts to improve intraoperative efficiency; assess the outcomes of these efforts, and propose standardized reporting of future studies.

Results: A total of 39 studies were identified that met inclusion criteria. These divided naturally into small (single operative team), medium (multi-operative team), and large (institutional) interventions. Most studies used time or money as their metric for efficiency, though others were used as well.

Conclusions: There is substantial opportunity to enhance operating room efficiency during the intraoperative period. Surgeons may have a particular role in procedural efficiency, which has been relatively unstudied. Common themes were standardizing tasks, collecting and using actionable data, and maintaining effective team communication.

© 2016 Elsevier Inc. All rights reserved.

Introduction

Hospitals and health systems must focus on improving efficiency to meet the increasing demands for high-quality, low-cost care. Although much has been written about the need and strategies to improve efficiency of the preoperative and post and/or interoperative periods, the intraoperative period— when the patient is in the operating room (OR)— has received less attention. Yet, the intraoperative period is the primary OR experience, the basis for procedure billing, and the period of time over which surgeons may have the most influence.

Most surgical dollars are spent in the OR, making this a high-priority target for efficiency efforts. As the public becomes more aware of differences in health care spending, hospitals may hold surgeons more responsible for controlling variable OR costs. Beyond this, surgeons have additional incentives for OR efficiency— time savings may translate to an earlier finish or the opportunity to perform more cases during the same block time. Because surgeons direct and perform surgical care on behalf of their patients, they are in the ideal position to ensure that efficiency improvements do not threaten patient care.
To raise surgeon awareness of OR efficiency (as has been previously done for quality6), this article summarizes currently published studies of intraoperative efficacy improvement, examines the outcomes of these efforts, and proposes standardization of reporting future efforts in the surgical literature.

Methods

Key search terms were determined by background reading on health care and manufacturing efficiency.8–11 We queried PubMed in April 2015 via the following search: [“operating room” OR “surgery” OR “surgical”] AND [“Efficiency” OR “Lean” OR “Six Sigma” OR “parallel processing” OR “process mapping” OR “process map” OR “value stream mapping” OR “value stream map” OR “total quality improvement”]. We excluded nonrelevant search results and articles not in English and then manually screened the remaining abstracts and their references for appropriate articles.

“Efficiency” is a widely used word in health care with multiple definitions; for this study, we focused on efforts to produce improvements in time, costs, or their proxies. We defined our inclusion criteria as any article describing a method to improve intraoperative efficiency and reporting results of an outcome measure. We defined the intraoperative time period to be that when the patient is in the operating room, including anesthesia time but not patient transport or room change-over time (“interoperative” time). Articles solely reporting preoperative, postoperative, or intraoperative efficiency were excluded as were articles solely regarding on-time starts, scheduling, ergonomics, cancellations, training, admissions, room change-overs, room airflow, quality measures, and work-life balance.

Each author independently selected articles based on inclusion criteria, and disagreements were settled with consensus. References of included articles were scanned for additional articles. After this iterative process was exhausted, the resultant articles were surveyed and categorized by focus and methodology. Level of evidence was assigned as a group from these articles based on the Agency for Healthcare Research and Quality National Guideline Clearinghouse guidelines. Two authors (A.F. and A.L.) then abstracted results from these studies and grouped them into the categories presented in the results.

Results

The initial search generated 26,798 results. Of these, 3602 remained after initial screening, and 182 articles and their references were screened individually for relevance. Of these, 37 studies were identified by all authors as meeting inclusion criteria; an additional eight articles were identified by at least one author, and of these, two were added based on consensus review for a total of 39 articles (Table). The PRISMA flowchart and the stratification for focus on intraoperative efficiency are summarized in Figure 1. For explanatory and supportive purposes, we also have cited an additional 49 review, analytical, and nonintervention descriptive articles in this article.

Of the 39 intervention articles, 29 (74%) used time as their metric for efficiency, 9 (23%) used financial measures, and 12 (31%) studies used other metrics such as tool reduction, case number, delays, and steps. Some studies used more than one metric and some included quality metrics as well. The most common factors studied were parallel processing (n = 7), lean management (n = 2), value stream/process mapping (n = 5), checklists (n = 2), OR redesign and environment (n = 2), Six Sigma (n = 2), and total quality management (n = 2). Most articles focused on the OR space or the surgical team and did not examine efficiency of the operative procedure itself.

Interventions were naturally partitioned into three categories based on scale: small (those that could be implemented in a single operating room potentially by a single surgeon or team); medium (those that require a surgical group or floor buy-in, support and change); and large (those that require major institutional buy-in, support and change). Common themes across these interventions were standardization, collecting and using actionable data, and maintaining effective communication.

Small-scale efficiency interventions

“Small” interventions can be implemented relatively quickly and can be considered first-line approaches to improving OR efficiency. A single surgeon or small groups of surgeons might initiate these interventions, which include:

Surgical workflow redesign
Attarian used interoperative and intraoperative workflow analysis to make multiple changes in staff behaviors and generate a case increase of 29% for total joint arthroplasties (from 2.35 to 3.04 average cases per OR per day12). Krasner standardized setup and introduced parallel task completion to reduce coronary bypass procedure time an average of 22 min (18%), anesthesia time 10 min (38%), and total OR time 67 min (21% of the initial average time of 314 min15). Such time savings may allow more cases to be completed if they are shorter (more revenue per OR day) or allow longer cases to be completed within standard shifts to avoid overtime (lower costs per OR day). Bender managed to accomplish both of these goals in a large academic medical center using a Six sigma approach that included input from members of the surgical team and administration; cases increased by 9% and overtime decreased from 7% to 4%, resulting in a 14% decrease in personnel costs and a 19% increase in OR revenue.14

Three studies applied process-mapping surgical procedures, which outline every step of the case and expected team tasks to decrease staff uncertainty and encourage anticipatory preparation. Chalian reduced operative time by 12% in 21 head and neck cancer resection cases by designating intraoperative pathways and standardizing planned instrumentation.13 Casaletto reduced operative time by 20% and reduced the number of surgical steps from 66 to 37 in eight carpal tunnel decompression cases.15 Lee mapped the intraoperative process of deep inferior epigastric perforator flap breast reconstruction and instituted simultaneous flap harvest and breast resection (parallel processing, Fig. 2). This change resulted in an average case length reduction of 16% (8.2 to 6.9 h for unilateral and 12.8 to 10.6 h for bilateral reconstruction) and reduced operative costs by 5%-12%.17
<table>
<thead>
<tr>
<th>Scale of the intervention</th>
<th>Author</th>
<th>Method</th>
<th>Study design</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Attarian</td>
<td>Process redesign</td>
<td>Time interrupted cohort. Level of evidence II</td>
<td>Number of cases increased by 29%</td>
</tr>
<tr>
<td></td>
<td>Bender</td>
<td>Six sigma</td>
<td>Nonrandomized trial, 24,193 cases over 2 y; level of evidence II</td>
<td>Number of cases increased by 9%, overtime decreased by 3%, 19% increase in OR revenue</td>
</tr>
<tr>
<td></td>
<td>Casaletto</td>
<td>Process mapping/redesign</td>
<td>Nonrandomized trial. Eight cases. Level of evidence II</td>
<td>Reduced operative time by 20% and reduced the number of surgical steps from 66 to 37 in eight carpal tunnel decompression cases</td>
</tr>
<tr>
<td></td>
<td>Cassera</td>
<td>Team familiarity</td>
<td>Cohort; 360 cases. Level of evidence III</td>
<td>Addition of 1 team member increased procedure time by predicted 15.4 min</td>
</tr>
<tr>
<td></td>
<td>Chalian</td>
<td>Pathway redesign</td>
<td>Nonrandomized trial; 21 cases. Level of evidence II</td>
<td>12% operative time decrease</td>
</tr>
<tr>
<td></td>
<td>Chin</td>
<td>Tool reduction</td>
<td>Cross-sectional study: 226 instrument trays, level of evidence II</td>
<td>Average instrument utilization rate found to be 27.8%, able to reduce instruments on trays by 57%</td>
</tr>
<tr>
<td></td>
<td>Engelmann</td>
<td>Standardized breaks</td>
<td>Randomized controlled trial; 51 cases. Level of evidence I</td>
<td>Frequent intraoperative breaks of 5 min every half hour did not increase operative time, and decreased adverse outcomes as well as surgeon cortisol levels.</td>
</tr>
<tr>
<td></td>
<td>Farrokhi</td>
<td>Lean methodology, 5s tool reduction</td>
<td>Nonrandomized controlled trial; 2766 cases. Level of evidence II</td>
<td>Reduction of surgical trays for minimally invasive spine surgery by 70% (197 tools to 58) and decrease operative time by 7 min</td>
</tr>
<tr>
<td></td>
<td>He</td>
<td>Team familiarity</td>
<td>Retrospective cohort; 1900 cases. Level of evidence III</td>
<td>Addition of one team member increased procedure time by predicted 34.7 min</td>
</tr>
<tr>
<td></td>
<td>Krasner</td>
<td>Parallel processing and standardization</td>
<td>Cohort; 549 cases. Level of evidence III</td>
<td>22-min surgical time saved; 10-min anesthesia time</td>
</tr>
<tr>
<td></td>
<td>Lain</td>
<td>IHI collaborative improvement, standardization, tool reduction, cycle time reduction</td>
<td>Cohort; 805 cardiac surgeries. Level of evidence III</td>
<td>26% cost reduction in coronary bypass DRG</td>
</tr>
<tr>
<td></td>
<td>Lee</td>
<td>Process mapping/redesign</td>
<td>Nonrandomized controlled trial; 150 patients, 100 before intervention. Level of evidence II</td>
<td>Unilateral group cost decrease of 10.2% and decreases of 1.3 h; bilateral group time decreases of 2.2 h</td>
</tr>
<tr>
<td></td>
<td>Lunardini</td>
<td>Tool reduction</td>
<td>Cross-sectional study: 38 instrument trays, level of evidence II</td>
<td>42% of instruments unused, 41% removed from tray with projected savings of $41,000 per year</td>
</tr>
<tr>
<td></td>
<td>Morris</td>
<td>Root cost analysis, process mapping</td>
<td>Retrospective cohort; 419 cases. Level of evidence III</td>
<td>Decreased instruments by 23%, decreased in OR non-operating time by 9 min (20%)</td>
</tr>
<tr>
<td></td>
<td>Ngu</td>
<td>Planning, streamlined supply chain and instrument trays, team building</td>
<td>Nonrandomized controlled trial; one surgical team. Level of evidence II</td>
<td>Instrumentation reduced from 113 to 72; doubling surgical volume per time</td>
</tr>
<tr>
<td></td>
<td>Nundy</td>
<td>Checklists</td>
<td>Nonrandomized controlled trial; 422 survey respondents. Level of evidence II</td>
<td>11% decrease in intraoperative delays, 15% decrease in communication breakdowns</td>
</tr>
<tr>
<td></td>
<td>Porta</td>
<td>Checklists (team assessment)</td>
<td>Cross-sectional survey; 11,342 cases. Level of evidence IV</td>
<td>9% decrease in mean delays, 39% decreased wasted time</td>
</tr>
<tr>
<td></td>
<td>Stockert</td>
<td>Tool reduction</td>
<td>Cross-sectional study: 49 procedures, 237 instrument trays, level of evidence II</td>
<td>Utilization rate for instruments was 13%-22%</td>
</tr>
<tr>
<td></td>
<td>Zheng</td>
<td>Team familiarity</td>
<td>Retrospective cohort; 587 cases. Level of evidence III</td>
<td>Addition of 1 team member increased procedure time by predicted 7 min</td>
</tr>
<tr>
<td>Medium</td>
<td>Al-Hakim</td>
<td>Tracking delay</td>
<td>Cross-sectional study; 31 cases. Level of evidence IV</td>
<td>Approximately 25% of the time observed was spent on preventable disruption and 60% of that preventable disruption was on nonvalue added activities</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Scale of the intervention</th>
<th>Author</th>
<th>Method</th>
<th>Study design</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Doherty</td>
<td>Standardization of team</td>
<td>Retrospective cohort; 101 cases. Level of evidence III</td>
<td>Standardize personnel on the operative team reduce procedure time by 47.1 min</td>
</tr>
<tr>
<td></td>
<td>Gitelis</td>
<td>Cost awareness</td>
<td>Non-randomized trial; 1014 cases (586 pre 428 post) level of evidence II</td>
<td>10% decrease in disposable costs for laparoscopic cholecystectomy, an annual savings of $27,000</td>
</tr>
<tr>
<td></td>
<td>Morris</td>
<td>Root cost analysis, process mapping</td>
<td>Retrospective cohort; 419 cases. Level of evidence III</td>
<td>Decreased instruments by 23%, decreased in OR non-operating time by 9 min (20%)</td>
</tr>
<tr>
<td></td>
<td>Overdyke</td>
<td>Tracking delays, education intervention</td>
<td>Cross-sectional survey. 1881 cases. Level of evidence IV</td>
<td>Reporting delays leads to less delays</td>
</tr>
<tr>
<td></td>
<td>Perkins</td>
<td>Timing auditing, tracking delays</td>
<td>Retrospective cohort; 180 cases. Level of evidence III</td>
<td>In OR to procedure start and turnover time identified as weaknesses</td>
</tr>
<tr>
<td></td>
<td>Stepaniak</td>
<td>Consistent team and type of procedure</td>
<td>Randomized controlled trial; 94 cases. Level of evidence I</td>
<td>Fixed teams and scheduling similar procedures sequentially reduces procedural time by an average of 10 min in the 94 hernia repair and laparoscopic cholecystectomies they observed</td>
</tr>
<tr>
<td></td>
<td>Stepaniak</td>
<td>Consistent team and type of procedure</td>
<td>Non-medical centers 1387 cases, level of evidence II</td>
<td>1387 bariatric procedures observed. Fixed teams reduced procedure duration by 10.8% or 4-13 min</td>
</tr>
<tr>
<td></td>
<td>Xu</td>
<td>Team familiarity</td>
<td>Cohort study: 754 procedures, 223 teams, 8 surgeons. Level of evidence III</td>
<td>Surgical team familiarity accounted for 16 min decrease in operative time after 10 collaborations</td>
</tr>
<tr>
<td></td>
<td>Large</td>
<td>Althausen Specialized team</td>
<td>Retrospective review; 2076 cases. Level of evidence III</td>
<td>Specialized trauma listologist decreased procedure time 20 min and cost about $600 versus general orthopedic surgeons</td>
</tr>
<tr>
<td></td>
<td>Friedman</td>
<td>Parallel processing</td>
<td>Non-randomized trial; 66 case studies, 72 controls. Level of evidence level II</td>
<td>Saved on average 9.6 min in sedate, block, and prep time</td>
</tr>
<tr>
<td></td>
<td>Hans</td>
<td>Parallel processing</td>
<td>Non-randomized trial; 335 cases. Level of evidence II</td>
<td>Nonoperative time decreased 11 min, one extra case possible per day with two ORs participating, with three ORs 2 extra cases possible</td>
</tr>
<tr>
<td></td>
<td>Harders</td>
<td>Parallel processing, multidisciplinary process redesign</td>
<td>Non-randomized trial; 239 cases, 23 surgeons. Level of evidence II</td>
<td>Decreased non-operative time by 23 min, decreased anesthesia time by 5 min</td>
</tr>
<tr>
<td></td>
<td>Kehoe</td>
<td>Supply chain management, lean</td>
<td>Case report; 1 hospital with 22 ORs. Level of evidence IV</td>
<td>Improved tray accuracy to over 99%</td>
</tr>
<tr>
<td></td>
<td>Rosenblatt</td>
<td>Supply chain management</td>
<td>Time interrupted cohort; 1318 (pre-intervention); 1367 cases (post-intervention). Level of evidence II</td>
<td>45% reduction in mean per case overage in comparable study periods</td>
</tr>
<tr>
<td></td>
<td>Small</td>
<td>Specialized OR</td>
<td>Randomized controlled trial; 1004 cases. Level of evidence I</td>
<td>7 min of operative time savings and a total savings of 19 min per procedure by using a specialized orthopedic OR</td>
</tr>
<tr>
<td></td>
<td>Smith</td>
<td>Parallel processing</td>
<td>Non-randomized controlled trial. 608 historical controls, 905 post-intervention cases, level of evidence II</td>
<td>Non operative time decreased 36 min, operative time decreased 14 min</td>
</tr>
<tr>
<td></td>
<td>Stahl</td>
<td>Specialized OR; parallel processing</td>
<td>Case-control; 182 specialized OR cases, 193 matched controls, level of evidence II</td>
<td>Decreased procedure time by 14 min, and total patient OR flow time by 29 min, this allowed for two additional cases per day</td>
</tr>
<tr>
<td></td>
<td>Torkkai</td>
<td>Parallel processing</td>
<td>Case-controlled; 57 cases preintervention, 77 cases postintervention. Level of evidence III</td>
<td>Non operative time decreased 45.6%, additional case was able to be added per day</td>
</tr>
<tr>
<td></td>
<td>Varu</td>
<td>Specialized OR</td>
<td>Case-controlled; 109 cases. Level of evidence III</td>
<td>Hybrid fixed-image fluoroscopy equipped ORs reduced contrast usage by 30 mL and operative time by 30 min on average in the 109 endovascular aneurysm repairs observed.</td>
</tr>
</tbody>
</table>
In addition to parallel processing, Lee’s process map included planned breaks and “no-handoff zones.” Planned breaks create a moment of rest during long cases and have been shown to help prevent mental fatigue. One study involving complex laparoscopic procedures found that in the 51 cases they studied, frequent intraoperative breaks of 5 min every half hour did not increase operative time and did decrease adverse outcomes and surgeon stress (as measured by cortisol levels).\textsuperscript{18}

No-handoff zones are time periods in a procedure in which the staff cannot change. In Lee’s study,\textsuperscript{17} the no-handoff zone started with the moment of flap harvest through the microvascular anastomosis (the flap ischemia time). Three studies each found that increased handoffs (as measured by team size) predicted increased operative time.\textsuperscript{19-21} These handoffs are primarily nurse-nurse (or nurse-tech) rather than surgeons. Studies examining surgeon handoffs are in conflict; He et al. found surgeon handoffs contributed to increased surgical time, whereas Cassera et al. found no effect.\textsuperscript{19,20} Regardless of the personnel who hand off, surgeons must determine the periods of the case during which handoffs will be most and least detrimental to case flow.

**Standardizing instruments and supplies**

Standardizing and reducing supplies and durable instruments have benefits outside and inside the OR by reducing operative costs, setup time, counting time, and turnover time. Farrokhi applied lean methodology to reduce surgical trays for minimally invasive spine surgery by 70% (197 tools to 58) and decrease operative time by 7 min.\textsuperscript{22} Lunardini held an “instrument fair” to discuss utilization of spine instruments, ultimately leading to a reduction of 41% and an estimated savings of $41,000 per y.\textsuperscript{23} Multiple other studies have reduced instruments by 19%-57%, leading to less clutter in the operating room, improved setup time, and reduced reprocessing costs.\textsuperscript{24-26} Our own study found that across multiple specialties, the utilization rate of instruments was 13%-22%,\textsuperscript{27} suggesting ample room for improvement.

**Team huddles**

Before and after each case, surgeons can use team huddles to improve efficiency. By reviewing the OR plan, goals, anticipated flow, and supply needs with the surgical team at the onset of the case, 11 surgeons at Johns Hopkins University reduced unexpected surgical delays from 36% to 25% in over 400 cases.\textsuperscript{28} Porta assessed the team’s performance after a case to understand intraoperative delays. This added no operative time and led to a 9% decrease in average delay and a 39% decrease in wasted OR time.\textsuperscript{29} Makary published a tutorial on these postoperative debriefings and suggested their use in identifying trouble areas.\textsuperscript{30}

**Medium-scale interventions**

“Medium” interventions require a whole OR floor or group to participate to see benefits. Data are collected across multiple practitioners and teams to identify outliers in need of improvement. These interventions require more staff buy-in to implement.

**Checklists**

The most widespread use of checklists in the OR today tends to focus on immediate preprocedural and postprocedural procedures. Fig. 1 — PRISMA diagram of literature search: (NB: The numbers listed for each exclusion type in “exclusion by inclusion criteria” add up to greater than total of 147 because some articles were excluded for multiple reasons.).
checks but extending them throughout the procedure is possible. Buzink piloted the Pro/cheQ, an interactive surgical workflow tool that displays checklists for each step of a laparoscopic cholecystectomy and found a 65% decrease in risk-sensitive events in 15 observed cases. Over time, however, they had difficulties with staff engagement; in their article,
they address the need to embed such checklists in the OR routine for a sustainable benefit. Russ reported on the development and validation of an observer-administered checklist ("METEOR") that assesses completion of key efficiency-related OR tasks during each stage of general surgical procedures.35 Although this was a research tool, it highlights key intraoperative tasks that could be targeted with a checklist.

Teaming
When surgeons regularly work with the same teams, cases run more efficiently due to nurses’ familiarity with tools and nomenclature, knowledge of preferences, and ability to anticipate needs. Stepaniak maintained fixed teams and scheduled similar procedures sequentially to reduce procedural time by an average of 10 min per case over 94 hernia repairs and laparoscopic cholecystectomies36 and in a separate study found that fixed teams and similar schedules reduced bariatric surgery duration by 10.8% or 4-13 min.37 Xu examined 754 cases of bilateral reduction mammoplasty procedures and found that surgical team familiarity with one another accounted for about 16-min reduction in operative time after 10 team collaborations.38 Similarly, Doherty reduced average procedure time by 47.1 min by standardizing the nursing staff over 49 complex head and neck cases.39 and Morris found working with familiar teams resulted in an average 20% (9 min) reduction in nonoperative in-room time per case.26

Data tracking
Perkins et al. tracked their operating room times for 180 pediatric otolaryngology cases to look for efficiency intervention targets. By comparing granular results on timing for each component of patient throughput (i.e., patient in-room to procedure start, procedure time, procedure end to room-out, and turnover time) to published benchmarks, they were able to focus their efficiency efforts only on the components that were prolonged.40

Overdyke et al. tracked specific interoperative and intraoperative delays to identify the most common sources of inefficiency for total quality improvement. By comparing granular results on timing for each component of patient throughput (i.e., patient in-room to procedure start, procedure time, procedure end to room-out, and turnover time) to published benchmarks, they were able to focus their efficiency efforts only on the components that were prolonged.40

Overdyke et al. tracked specific interoperative and intraoperative delays to identify the most common sources of inefficiency for total quality improvement.41 They found decreased delays after their interventions, many of which
**Sensors are becoming ubiquitous in health care settings. In the OR, this commonly includes radiofrequency identification tracking of**
involved simply notifying the right people of their performance. Al-Hakim and Gong found by tracking delays in the OR that about 25% of intraoperative delay time was spent on preventable disruption and 60% of those disruptions were for unnecessary activities or those that should have been performed before the procedure.\textsuperscript{42}

**Awareness of costs**

Gitelis found that educating surgeons about the price of disposable tools resulted in a 10% decrease in disposable costs for laparoscopic cholecystectomy for an annual savings of $27,000.\textsuperscript{43} Our own institutional experience has been even more significant, with a decrease in >$500,000 in annual costs of disposable instruments due to a cost-awareness campaign across just four surgical specialties.

**Large-scale interventions**

“Large” interventions require institutional cooperation and major investment to implement. These include reorganizing supply-chain management, creating designated teams for specialized tasks, and redesigning the OR space itself.

**Supply chain management**

Supplies are a voluminous and costly component of surgical work; hospitals may spend 50% of OR budgets on supplies,\textsuperscript{44} and this has prompted several studies aimed at reducing supply-related costs and delays. Intraoperatively ensuring that the right items are available and that unnecessary items remain unopened has the potential to reduce OR equipment delays, decrease labor costs to pull and restock unused items, and improve doctors’ and nurses’ focus on clinical care.\textsuperscript{44-47} To reduce the presence of unnecessary items, the surgical team can estimate instrument needs from past cases\textsuperscript{46} and can track wasted (opened-but-unused) supplies.\textsuperscript{48} Using this information to revise pick lists and standardize OR setups led Rosenblatt to decrease wasted material costs by 45%\textsuperscript{49} across just four surgical specialties.

Tracking supplies with barcodes or radiofrequency identification (RFID) enhances the speed and accuracy of data collection for efficiency interventions by linking supplies with specific patients and providers and generating actual utilization data.\textsuperscript{50-55} This tracking technology can continuously monitor supplies and deliver case carts “just-in-time” to reduce operative waiting time as well as holding costs related to excess inventory.\textsuperscript{44} Such tracking software can also be used on durable instruments, to maintain tray accuracy and eliminate delays due to missing instruments\textsuperscript{56} and on personnel, to drive insights on workflow.\textsuperscript{57}

**Specialization**

Some groups have implemented specialized personnel, programs, instruments, and ORs to improve efficiency.\textsuperscript{58-61} Such interventions are only possible at medical centers with justifiable volume but have the potential to greatly improve time and cost savings. Small reduced operative time by 7 min and total room time by 19 min per procedure by using a specialized 6-room orthopedic OR unit with dedicated teams.\textsuperscript{58} Althausen examined the effect of a specialized traumatologist for surgical fracture care compared to a general orthopedic surgeon at a level II trauma center. In the 2076 cases, they studied, the outcomes were comparable, but the traumatologist’s procedures were shorter—by approximately 20 min ($P = 0.0001$)—and demanded fewer labor, supply, and implant costs.\textsuperscript{60}

**Space redesign and parallel processing**

Perhaps, the largest approach to improving efficiency is to physically redesign the OR. Massachusetts General Hospital built its OR of the Future (ORF) to study the effect of space interventions on efficiency.\textsuperscript{62} In the ORF induction and early-recovery rooms adjoin to improve patient flow; monitors and sensors help with easy reconfiguration. To improve throughput, specialized gurneys double as patient beds, thereby eliminating transfers. Although ORF requires an additional staff member, the workflow redesign generated enough capacity to perform two additional procedures daily.\textsuperscript{62,63} The capacity increase was due to reductions in nonoperative time by about 30 min per case by parallel processing OR turnover with patient recovery and the next patient’s induction (Fig. 2).

Multiple studies have examined the effect of parallel processing on efficiency in the OR and found a savings of 5-36 min from in-room anesthesia or nonoperative time. Freidman saved an average 9.6 min in sedation, blocking, and prep time,\textsuperscript{64} Smith saved an average 36 min of nonoperative time (a 50% savings),\textsuperscript{55} and Harders saved 23 min of non-operative time and 5 min in anesthesia time.\textsuperscript{66} Importantly, this time reduction does not seem to affect anesthesia quality and may actually allow for a less hurried induction while still saving overall time.\textsuperscript{67}

These time savings result in real additional capacity (which can translate to revenue increase). Torkki and Hanss each found that a separate induction room allowed an additional case to be added to a normal surgical day.\textsuperscript{58,65} Hanss also showed that this effect was more powerful when more ORs participated in parallel processing (going from two to three participating ORs resulted in an increase from one to two additional surgical procedures being possible in a standard day with the same procedural mix).\textsuperscript{58} The number of additional personnel needed to run these parallel induction rooms was 1.5 to 2.\textsuperscript{68}

The benefits of additional capacity are balanced against the combined upfront capital investment in space redesign and ongoing costs of additional personnel. Marjamaa found that infrastructure costs can be avoided by performing parallel induction techniques within existing space\textsuperscript{70} and also that efficiency savings hold even in scenarios with centralized induction areas.\textsuperscript{71}

---

patients, supplies, and personnel but could also be envisioned to include computer vision, audio, and wearables that track elements such as instrument use, economy of motion, or stress. **“Interventions may affect certain parts of the procedure more than others. Defining these discreet elements is important. See Fig. 3. **“Although patient is anesthetized but surgical team is not actively operating due to a disruption or delay.
However, saving a few minutes of OR time may not always translate to additional cases.25 Using a mathematical model based on cases in the ORF and normal ORs, Sokal found that parallel processing would save enough time for additional procedures in only 26% of potential surgeon-case combinations.73 Furthermore, they noted that without increased Post Anesthesia Care Unit space, increased OR turnover can lead to shifting the bottleneck in efficiency.73

In addition to parallel processing, whereby tasks are moved outside the OR, space redesign can also introduce new functions into the OR. "Hybrid rooms" can include fluoroscopy, magnetic resonance imaging, and computed tomography imaging capabilities to reduce wait time and eliminate the need for patient transportation during procedures.74-77 For instance, Varu found fixed-image fluoroscopy-equipped ORs reduced operative time by an average 30 min in 109 endovascular aneurysm repairs.77

Discussion

Although much of the money spent in surgical care occurs in the OR; few published studies focus on this portion of the workflow. It may be that the preoperative, postoperative, and intraoperative periods are more standardized, easier to track, and represent the "low hanging fruit" for efficiency improvement. Surgery is highly human and must respond to patients’ anatomy, physiology, and pathology. This variability is a roadblock to efficiency improvement and highlights the need for more surgeons to get involved in efficiency interventions; surgeons have firsthand insight into the effect that any intervention has on the care of individual patients.

The timepoints, cost methodology, and outcomes measures were inconsistent across the studies in this review, and most reports lacked details that would facilitate replication in other centers. Nicolay found similar deficiencies in studies on quality improvement in the OR. Nevertheless, articles cited in this review give important clues as to how manufacturing techniques can be useful tools for the OR.

Standardization has long been an approach to improving workflow in manufacturing because it improves consistency and speed with repetition. Although patients may vary, the major steps of a given procedure are usually consistent and outlining even these can help teams and reveal opportunities for improvements in efficiency; surgeons have firsthand insight into the effect that any intervention has on the care of individual patients.

Figure 4 outlines the steps for designing and implementing an OR efficiency intervention, as well as the key reporting measures for future publications. As more studies of OR efficiency are conducted, ensuring complete and standardized reporting can allow for cross-study comparisons, meta-analyses, and more reliable inferences from data produced by multiple institutions.

Limitations

Data used to assess efficiency do not tell the whole story. A simultaneous focus on improving or maintaining the quality of care must occur in any health care efficiency intervention. Our choice to focus only on the intraoperative period means that we have excluded many successful
workflows and solutions for improving intraoperative efficiency can occur on many levels based on the required level of resources and institutional support. Data transparency and communication are critical to intraoperative improvements, and any intervention should be conducted in the context of overall patient care. Intraoperative efficiency is an emerging science that must balance workflow standardization with individual patient care, and surgeons must therefore play a central role in developing future efficiency innovations.

**Conclusion**

Approaches to improving intraoperative efficiency can occur on many levels based on the required level of resources and institutional support. Data transparency and communication are critical to intraoperative improvements, and any intervention should be conducted in the context of overall patient care. Intraoperative efficiency is an emerging science that must balance workflow standardization with individual patient care, and surgeons must therefore play a central role in developing future efficiency innovations.

**Acknowledgment**

The authors wish to thank Tomoko Ichikawa and Marcie Cooperman, both of the Illinois Institute of Technology Institute of Design, Chicago, IL, for preparation of Figures 2-4.

Author contributions: All authors contributed to the design, research, analysis, and writing of this work.

**Financial disclosures**

The authors have no disclosures.

**References**


69. Torkki PM, Marjamaa RA, Torkki MI, et al. Use of anesthesia induction rooms can increase the number of urgent orthopedic cases completed within 7 hours. Anesthesiology. 2005;103:401–405.