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Research review

Prolonged operative duration is associated with complications: a systematic review and meta-analysis

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ABSTRACT

Background: The aim of this study was to systematically synthesize the large volume of literature reporting on the association between operative duration and complications across various surgical specialties and procedure types.
Methods: An electronic search of PubMed, Cochrane Central Register of Controlled Trials, and Cochrane Database of Systematic Reviews from January 2005 to January 2015 was conducted. Sixty-six observational studies met the inclusion criteria.
Results: Pooled analyses showed that the likelihood of complications increased significantly with prolonged operative duration, approximately doubling with operative time thresholds exceeding 2 or more hours. Meta-analyses also demonstrated a 14% increase in the likelihood of complications for every 30 min of additional operating time.
Conclusions: Prolonged operative time is associated with an increase in the risk of complications. Given the adverse consequences of complications, decreased operative times should be a universal goal for surgeons, hospitals, and policy-makers. Future study is recommended on the evaluation of interventions targeted to reducing operating time.

Introduction

Worldwide, an estimated 234 million major surgical procedures are performed every year, making surgical care an essential part of health care.[1] Surgical procedures are associated with considerable risk of complications (e.g., infections) that adversely affect patient outcomes and increase health care costs.[2,3] The risk of complications is two to five times greater in surgery than in general medicine, and approximately 40% of in-hospital complications are related to surgical procedures.[4,5] Although it is difficult to generate precise estimates, the risk of complications has been noted to range from 3% to 17% among surgical patients in developed countries.[6]

In recent decades, a growing body of evidence has suggested that surgical or operative duration is an independent and potentially modifiable risk factor for complications. For

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instance, a positive association between the duration of surgical procedures and complications such as surgical site infection (SSI), venous thromboembolism (VTE), bleeding, hematoma formation, and necrosis has been reported in prospective and retrospective studies across various surgical procedures.[6-10] Similarly, a systematic review by Visser *et al.*[5] identified, categorized, and ranked various patient- and surgery-related risk factors for complications; prolonged operative duration was among the top three surgery-related factors. However, the review by Visser *et al.* only identified six studies that assessed operative duration and its relationship with surgical-related complications; three studies reported a statistically significant association, whereas three studies reported a nonstatistically significant association.

To our knowledge, a comprehensive review assessing and quantifying the association between operative duration and a variety of complications across surgical specialties has not been conducted. Because complications lead to worsened clinical status, emotional and financial burden for patients and families, and additional health care costs, the aim of this systematic review was to systematically synthesize the large volume of literature reporting on the association between operative duration and complications, across several surgical specialties and procedure types, to help inform decision-making, planning, and management. We hypothesized that prolonged operative duration would be associated with a greater risk of developing complications across surgical specialties.

Methods

Search strategy

PubMed, the Cochrane Central Register of Controlled Trials, and the Cochrane Database of Systematic Reviews were searched for relevant literature on April 19, 2015. The search strategy was limited to articles published in the English language between January 2005 and January 2015 (the search strategies are provided in Appendix A). Reference lists of retrieved articles and relevant reviews were hand-searched. The search was also supplemented through the "similar articles" search in PubMed to identify unique articles.

Study selection

The PICOS categories (i.e., population, intervention, comparator, outcomes, and study design) were used to define study inclusion criteria. All published meta-analyses, systematic reviews, randomized controlled trials, and observational studies (prospective or retrospective) reporting an effect measure for the association between operative duration and complications in humans, for all surgery types, were considered for inclusion. Studies were excluded if they were published in the form of case reports, letters, comments, or editorials or were conducted in nonhuman models. Based on the inclusion criteria, the eligibility of each publication was evaluated in a title and abstract review. If the abstract and title review suggested potential eligibility, a full-text screening followed. Reasons for exclusion were documented.

Data extraction

Two reviewers extracted data from full-text articles independently. The following study details were extracted: study authors, publication year, study time frame, sample size, study design, number and types of surgeries, complications and their rates, effect measures for the association between operative duration and complications, mean operative duration, and definitions of included complications, where available. Most studies reported odds ratios (ORs); however, a small number of studies reported risk ratios or hazard ratios. We extracted both adjusted and unadjusted effect measures and their 95% confidence intervals; however, only adjusted effect estimates were used for meta-analyses. The variables that were controlled for in adjusted effect measures varied across studies but often included a range of patient and surgical factors. Typically, increased operative duration was defined categorically relative to a cut point (e.g., <1 h or >1 h) or per minute(s) of surgery. If study results were reported in minutes, results were converted to hours for consistency. Data were reported if an association was noted for complications varying in severity or time point (e.g., major or minor complications and intraoperative or postoperative complications), and for various types of complications (e.g., wound, cardiovascular, and respiratory complications), where available.

Data synthesis and statistical methods

Several meta-analyses were performed to quantify the association between operative duration and complications for studies that reported adjusted effect measures. No additional adjustments, outside of those data provided from the original studies, were conducted in the meta-analyses. First, studies that reported adjusted ORs, the associated 95% confidence intervals, and operative time thresholds that fell within 20% of the hour were pooled by hourly operative time thresholds (e.g., <1 h *versus* >1 h). For example, if a study reported thresholds of ≥ 50 or <50 min, this study would have been included in the 1-h time threshold analysis. Second, studies that reported increments of operative time (risk of complications per minute, per 30 min, etc.) were pooled. Third, all studies that reported an adjusted OR were pooled and analyzed by surgical specialty. We used the DerSimonian–Laird random-effects model for the meta-analyses. Heterogeneity was assessed using Q statistic and I^2. Fourth, a meta-regression analysis was used to further validate the effect of incremental increases of operative time on the risk of complications. All analyses were conducted using STATA (version 14.2).

Results

Overall, 4556 studies—4343 through database searches and 213 through PubMed "similar" and manual bibliography searches—were identified (Fig. 1). Of the 4556 studies, 2349 were excluded following title and abstract screening. As such, 2207 studies underwent full-text review; 2141 studies were excluded for reasons detailed in Figure 1. In total, seven prospective and 59 retrospective observational studies were

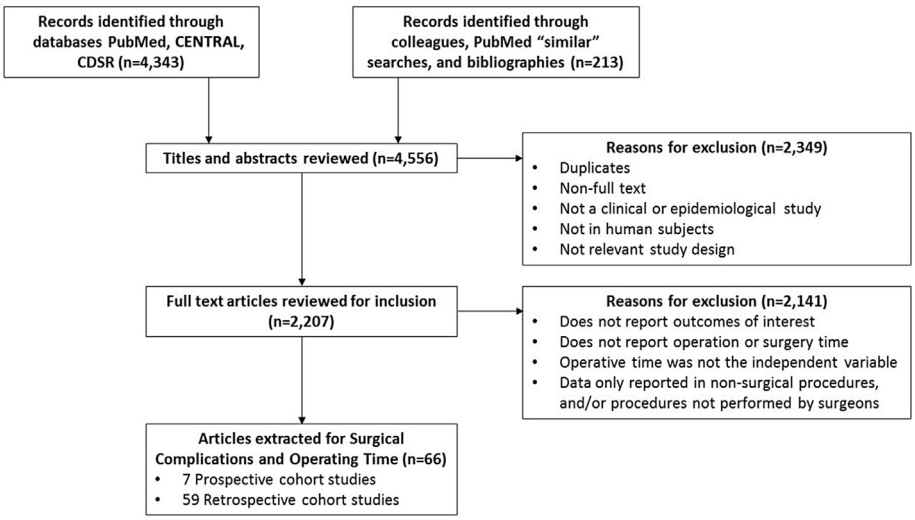

Fig. 1 – PRISMA diagram of study selection in the systematic literature search. CENTRAL = Cochrane Central Register of Controlled Trials; CDSR = Cochrane Database of Systematic Reviews.

included in this systematic review and described qualitatively in more detail in Appendices B and C.[7-72] A total of 33 studies had sufficient information to be included in the meta-analyses (list of studies included in the meta-analyses is provided in Appendices D and E).

The sample size of the included studies for the systematic review ranged from 49 to 299,359 patients. Based on the American College of Surgeons (ACS)[73] categorization of surgical specialties, the majority of studies assessed surgical procedures in general (26%), urological (24%), and colorectal (11%) specialties (Table 1). More than half of the included studies (55%) used an institute- or society-based definition, or an international classification grading system for complications. Many studies referenced the ACS National Surgical Quality Improvement Program definitions for complications (29%) or the Clavien-Dindo classification of complications (18%). Details of complication definitions by study are provided in Appendix B. Approximately 59% of the included studies reported a follow-up time of 30 d following surgery, whereas the remaining studies reported a 90-d follow-up (11%), did not report a follow-up (23%), or reported other follow-up periods such as 35 d (7%). Most studies originated from the United States (56%) or Japan (14%). Examples of other regions included Germany (5%), Thailand (3%), Australia (3%), and the United Kingdom (2%).

Table 1 – Distribution of surgical specialties across included studies*.

Surgery type	Studies included (n = 66)
	n (%)
General surgery	17 (26)
Colorectal surgery	7 (11)
Urological surgery	16 (24)
Plastic and maxillofacial surgery	6 (9.1)
Obstetrics and gynecology surgery	4 (6.1)
Orthopedic surgery	2 (3.0)
Neurological surgery	3 (4.6)
Otolaryngology surgery	2 (3.0)
Thoracic surgery	4 (6.1)
Multiple surgical specialties	5 (7.6)

*Surgical specialty based on the American College of Surgeons categories of specialties; (https://www.facs.org/education/resources/medical-students/faq/specialties).

In this systematic review, prolonged operative duration was associated with a statistically significant increase in the risk of complications. Specifically, 81% (48/59) of retrospective cohort studies and 71% (5/7) of prospective cohort studies reported one or more statistically significant results. In more than half (54%) of the included studies, the risk of complications was reported to be 10% or higher (Appendices B and C). The meta-analysis showed that the likelihood of experiencing a complication approximately doubled with operative time exceeding cutoffs of 2 or more hours (Table 2, Fig. 2, Appendix D). Meta-analyses also demonstrated that the likelihood of developing a complication increased with increasing operative time increments (i.e., 1% for every 1-min, 4% for every 10-min, 14% for every 30-min, and 21% for every 60-min increase in operative time). This relationship remained statistically significant across all time increments except for 10 min (Table 2, Appendix E). A meta-regression analysis on operative time increments validated these results (Fig. 3).

General surgery

Seventeen studies reported the association between operative duration and the risk of complications in general surgeries (e.g., cholecystectomy, liver transplant, and hepatectomy). Ten studies reported a mean operative time that ranged from 1.8 to 10.0 h. The risk of complications varied from 1.2% to 71%. Frequent complication types included SSI, wound infection or dehiscence, bleeding, pneumonia, urinary tract infection, and renal failure. A statistically significant association

Table 2 – Pooled adjusted ORs for complications by operative time threshold or increasing increments of time.

Subgroup/category	Pooled OR	95% CIs		*P* for difference	I^2 (%)	No. of studies
Operative time thresholds						
≥2 h *versus* <2 h	1.99	1.41	2.83	<0.001	58.6	5
≥3 h *versus* <3 h	1.46	0.77	2.75	0.243	83.2	4
≥4 h *versus* <4 h	1.95	1.51	2.54	<0.001	0.0	4
≥5 h *versus* <5 h	2.36	1.92	2.91	<0.001	0.0	5
≥6 h *versus* <6 h	2.01	0.99	4.06	0.053	63.7	3
Increasing increments of operative time						
Per 1-min increase	1.01	1.00	1.01	<0.001	71.1	5
Per 10-min increase	1.04	0.99	1.09	0.101	74.4	2
Per 30-min increase	1.14	1.12	1.16	<0.001	0.0	2
Per 60-min increase	1.21	1.14	1.29	<0.001	46.5	3

between operative duration and complications was reported in 14 (82%) studies. The meta-analysis of studies that reported adjusted ORs for incremental increases in operative time ($n = 6$) or for time cutoffs ($n = 6$) showed a statistically significant positive association between operative time and complications (Table 3).

Colorectal surgery

In the seven observational studies reviewed, the risk of complications ranged from 2.4% to 16.3%. Common complications included SSI, sepsis, bowel obstruction, wound infection, bleeding, and intra-abdominal abscess. Four studies reported the mean operative time that ranged from 2.4 to 4.6 h. Four studies (57%) reported a statistically significant association between operative duration and complications. The meta-analysis demonstrated an increased likelihood of developing a complication across studies reporting operative time thresholds ($n = 5$); however, this association was not statistically significant (Table 3).

Urological surgery

The risk of complications ranged from 1.1% to 57% in the 16 observational studies assessing urological surgery (i.e., typically nephrectomy, cystectomy, or adrenalectomy). Complications were typically postoperative and included bleeding or wound and cardiac, neurologic, and respiratory complications. Thirteen studies reported the mean operative time that ranged from 2.0 to 8.4 h. Results were statistically significant for the association between operative duration and complications in thirteen (81%) studies. The meta-analysis demonstrated that operative time was associated with a statistically significant increase in the likelihood of developing a complication, regardless of whether operative time was defined in increments of time ($n = 7$) or through time thresholds ($n = 5$).

Plastic and maxillofacial surgery

Of the six observational studies assessing procedures from the plastic and maxillofacial surgical specialty (i.e., free-flap surgery, microvascular free tissue transfer, and panniculectomy), the risk of complications ranged from 2.8% to 46.0%. Common complications included flap failure, SSI, wound dehiscence and infection, deep vein thrombosis, and reintubation. Four studies reported a statistically significant association between prolonged operative time and complications. Across the studies that reported a mean operative time in this surgical specialty ($n = 4$), a range of 2.4-10.1 h was observed. The meta-analyses for studies that reported incremental increases in operative time ($n = 2$) or operative time cutoffs ($n = 2$) demonstrated positive associations between operative time and complications; however, the associations were not statistically significant (Table 3).

Obstetrics and gynecology surgery

Across the four studies reviewed for this specialty, the risk of complications ranged from 2.1% to 29.0%, and complications included infected lymph cyst, wound infections, SSI, ileus, and renal complications. The association between operative duration and complication subtypes was significant in all studies. The mean operative time was reported by three studies; it ranged from 2.8 to 4.2 h. The meta-analysis of two studies showed an 86% statistically significant increase in the likelihood of experiencing a complication with increased operative time (Table 3).

Orthopedic surgery

The risk of complications varied from 2.2% to 5.6% in the two observational studies reported for this surgical specialty (i.e., total hip or total knee arthroplasty). Types of complications included SSI, urinary tract infection, cardiac complications, pneumonia, renal failure, and sepsis. Results were statistically significant for the association between prolonged operative duration and complications across both studies.[18,54] The mean operative time ranged from 1.6 to 1.7 h across these studies. The meta-analysis ($n = 2$) showed a statistically significant 67% increase in the likelihood of experiencing a complication with prolonged operative duration (Table 3).

Neurological surgery

Of the three observational studies reviewed for this specialty, the risk of complications, where available, ranged from 1.5% to 27.4%. Common complication types included

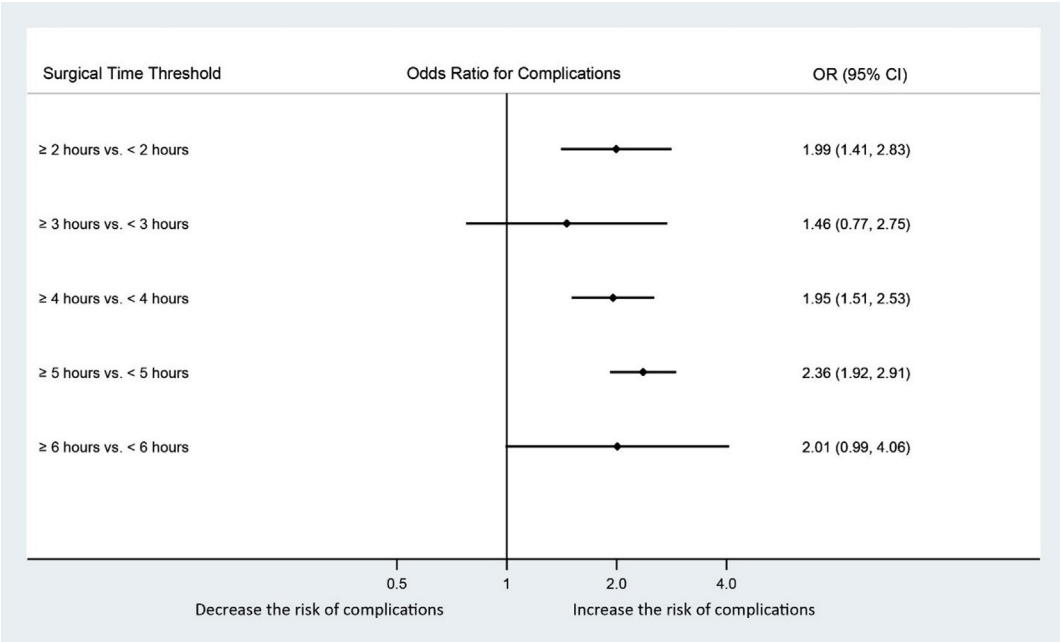

Fig. 2 – Pooled adjusted odds ratios (ORs) with 95% confidence intervals (CIs) for complications by operative time threshold. (Color version of figure is available online.)

postcraniotomy meningitis, extracranial infection, pulmonary embolism, and pneumonia. A statistically significant association between prolonged operative duration and complications was reported across all studies. The mean operative time ranged from 2.6 to 2.7 h across the studies that reported this statistic ($n = 2$). A meta-analysis of the studies reporting increments of operative time ($n = 2$) showed a positive association between complications and increasing operative time; however, this association was not statistically significant. A single study reported operative time cutoffs and a 70% increase in the likelihood of developing postcraniotomy meningitis if surgery lasted longer than 4 h[42] (Table 3, Appendix B).

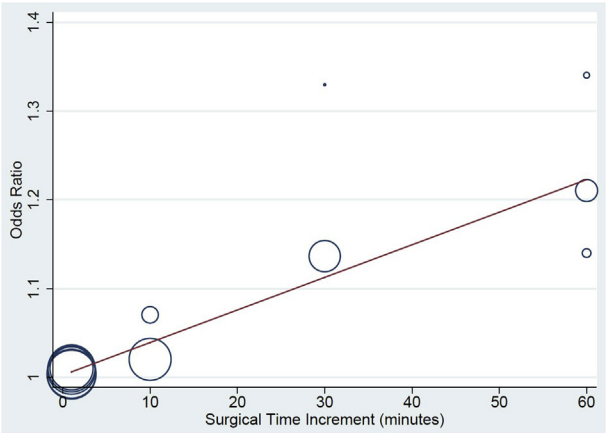

Fig. 3 – Bubble plot for meta-regression of risk of complication and duration of surgery. The solid line represents the weighted regression line. The circles indicate ORs in each study. The circle size is proportional to the weight of the studies. (Color version of figure is available online.)

Otolaryngology surgery

There were two studies that evaluated otolaryngology procedures (i.e., esophagectomy). The risk of complications, including pneumonia and postoperative hypobilirubinemia, varied from 23% to 36%. Sunpaweravong *et al.*[66] reported a mean operative time of 8.8 h. The authors noted a statistically significant association between prolonged operative duration and risk of complications with an adjusted relative risk ranging from 2.46 to 3.25 depending on the operative time threshold (Appendix B). This translates to an estimated threefold increased risk of complications when exceeding the above defined time cut points.

Thoracic surgery

Of the four observational studies reviewed in this specialty, the risk of complications, including air leaks, pneumonia, hypoxia, ventilator requirement, and cardiac-related complications, ranged from 1.8% to 34.5%. The mean operative time ranged from 2.4 to 3.7 h and was reported by three studies. A meta-analysis of studies reporting the increments of operative time ($n = 2$) showed a positive association between complications and operative time; however, this association was not statistically significant (Table 3). One study reported a statistically significant increase in likelihood of complications if the operative duration was equal to or exceeded 4 h[31] (Table 3).

Multiple surgical specialties

Five studies assessed procedures from multiple surgical specialties (cholecystectomy, hernia repair, mastectomy, etc.). A meta-analysis of three studies that reported adjusted ORs for increments of operating time showed that increased operative

Table 3 – Pooled adjusted ORs for complications and increased operative time, by surgical specialty.

Outcome	Pooled OR	95% CIs		P for difference	I^2 (%)	No. of studies
General surgery						
Increments of operative time	1.01	1.00	1.01	0.001	80.7	6
Operative time thresholds (cutoff)	2.45	1.69	3.55	<0.001	65.7	6
Colorectal surgery						
Increments of operative time	1.00	1.00	1.01	<0.001	-	1
Operative time thresholds (cutoff)	1.47	0.88	2.44	0.141	77.7	5
Urology						
Increments of operative time	1.02	1.01	1.03	0.011	76.8	7
Operative time thresholds (cutoff)	2.31	1.31	4.09	0.004	46.8	5
Plastic and maxillofacial surgery						
Increments of operative time	1.07	0.81	1.39	0.651	92.0	2
Operative time thresholds (cutoff)	2.47	0.89	6.89	0.084	78.3	2
Obstetrics and gynecology	1.86	1.43	2.42	<0.001	0.0	2
Orthopedic surgery	1.67	1.42	1.96	<0.002	100.0	2
Neurological surgery						
Increments of operative time	1.06	0.94	1.20	0.351	86.4	2
Operative time thresholds (cutoff)	1.70	1.07	2.71	0.026	-	1
Thoracic surgery						
Increments of operative time	3.13	0.46	21.42	0.245	54.3	2
Operative time thresholds (cutoff)	2.51	1.04	6.07	0.041	-	1
Multiple surgical specialties						
Increments of operative time	1.14	1.01	1.28	0.031	98.8	3
Operative time thresholds (cutoff)	2.20	1.30	3.71	0.003	-	1

time is associated with a statistically significant increase in likelihood of developing a complication (Table 3). Only one study reported an operative time cutoff; this study reported that the odds for complications were two times greater among general, vascular, and urological surgical patients that experienced an operative duration of ≥3.8 h *versus* <3.8 h[38] (Table 3).

Discussion

The findings of the systematic review ($n = 66$) demonstrated a robust association between prolonged operative time and complications across surgical specialties. In fact, most included studies (80%) reported a statistically significant association. The meta-analysis of a subset of these studies demonstrated that the likelihood of complications approximately doubled with prolonged operative duration, and results were statistically significant across several operative time thresholds (e.g., ≥2 *versus* <2 h and ≥4 *versus* <4 h). Similarly, the likelihood of developing complications increased with increasing increments of operating time (i.e., increased by 1% for every 1-min [$P < 0.001$], 4% for every 10-min [$P = 0.101$], 14% for every 30-min [$P < 0.001$], and 21% for every 60-min [$P < 0.001$] increase in operative time). Notably, the meta-regression analysis verified these results.

The aforementioned results corroborate the findings from previous reviews that have assessed the association between operative duration and complication types. For instance, a systematic review by Cheng *et al.*[74] determined that there was a significant positive association between operative time and the likelihood of developing SSIs. Furthermore, the authors suggested that the likelihood of developing SSIs increased linearly with increasing time increments across various surgical specialties; there was a 13%, 17%, and 37% increase in the likelihood of developing SSI for every additional 15, 30, and 60 min of operative time, respectively. However, as compared to the systematic review by Cheng *et al.*, the effect estimates from our study were lower. These differences are likely attributable to alternative methods between the two studies; although we assessed and quantified a variety of complications (SSI, VTE, necrosis etc.), Cheng *et al.*[74] exclusively focused on SSIs. It is well established that certain complications, such as SSIs, are strongly and intrinsically associated with prolonged operative duration across many surgical specialties. In fact, SSIs are likely to occur because of time-related factors such as prolonged microbial exposure.[74,75] However, other complications including renal failure and myocardial infarction do not have well-defined relationships with operative duration; results are inconsistent across studies and vary across surgical specialties.[76] Thus, it is possible that pooling of all complications across all surgical specialties diluted the effect estimates in our study.

Within surgical specialties, the association between operative time and complications was statistically significant for general, urological, obstetrics and gynecology, and orthopedic

surgical specialties, irrespective of how an increase in operative time was defined. The factors contributing to the varying strengths of associations between operative time and complications are likely to be multifaceted and differ across surgical specialties. These can include preoperative (e.g., preoperative length of stay), intraoperative (e.g., average surgical duration and operating technique), and postoperative (e.g., postoperative length of stay and wound drain) factors.[75,77] In addition, the patient population undergoing surgical procedures and the type of surgery (e.g., open *versus* closed) can clearly differ by surgical specialty and variably affect the risk of complications.[75,77-79] In thoracic and orthopedic surgery, for example, candidates are often elderly and have substantial comorbidity burden—biologically plausible factors that make these patients especially vulnerable to complications.[80,81] In general surgery, Procter *et al.*, 2010[57] (i.e., the largest study included in our analysis, $n = 299{,}359$ surgeries), demonstrated that across all procedures, complication risk, defined as infectious complications, increased independently for each half-hour of operative duration, after adjustment for 38 patient risk variables including operation type and complexity. Furthermore, to reduce procedure variability, Procter *et al.*[57] refined their analysis in isolated laparoscopic cholecystectomy cases and found that adjusted results remained significant, with double the risk of infection after 1-1.5 h of surgery compared with 30 min or less. Our study adds to Procter et al.'s study[57] by expanding on the surgical specialties as well as the definition of complications, while using adjusted results to limit the potential influence of confounders. Understanding how all of these additional risk factors can impact the association between operative time and complication risk warrants further investigation. Irrespective of this knowledge, targeting surgical procedures or specialties that portray a stronger association between operative duration and complications, through modifiable factors, should be prioritized.

The exact mechanisms underlying the positive association between complications and prolonged operative durations are not fully understood and are likely to vary for different types of complications. For example, the correlation between SSIs and prolonged operative duration can be attributable to various time-related factors such as prolonged microbial exposure, diminished efficacy of antimicrobial prophylaxis over time, increased tissue retraction leading to tissue ischemia, necrosis, and desiccation, and increased opportunities for violations in sterile technique.[78,82-85] In contrast, the increased risk of VTE due to prolonged operative duration has been linked to factors such as increased coagulation, blood stasis, and endothelial damage resulting from longer surgical procedures.[86-89] Prolonged operative times are also associated with increased surgical team fatigue and extension of anesthesia duration—factors that enhance the risk for many different types of complications.[90-92] However, it is also plausible that complications can, in reverse, prolong the duration of surgical procedures and hence contribute to the positive association between operative duration and complication risk. This notion is more relevant to operative complications, such as surgical bleeding, that occur during the actual procedure rather than postoperative complications such as infection, VTE, and pneumonia. However, adjusted ORs were used in our meta-analyses to control for factors, such as patient comorbidity, that could have imbalanced comparison groups with respect to intraoperative complication risk. Furthermore, longer operative times can be indicative of more complex or difficult surgeries (e.g., patients with multiple comorbidities), which would expectedly yield higher rates of complications.[93] Thus, we do not recommend a sacrifice of patient safety for surgical speed. However, surgeons, surgical staff, hospitals, and policy-makers can positively impact patient outcomes through simple and practical changes that reduce operative time.[20] At the surgeon and surgical staff level, strategies that improve technical skill and operative efficiency (e.g., mentorship programs) should be employed where feasible. For example, Procter *et al.*, 2010,[57] reported that poor communication can be a barrier to operative efficiency and has been addressed by the World Health Organization's Surgical Safety Checklist and shown to reduce complications. Also, it was noted that operative duration is longer in the presence of surgical trainees, and increasing attending supervision of surgical trainees during cases has been shown to be cost-effective.[57]

Furthermore, methods such as strict adherence to complication prevention measures, detailed and substantial preoperative planning (e.g., addressing team familiarity with surgical procedure and equipment before surgery), and usage of emerging technologies that promote safety and lessen operative duration can help reduce time.[94-96] At the hospital level, work flow should be optimized, surgeon and surgical staff fatigue should be minimized through innovative scheduling programs, intraoperative teaching should be carefully planned, and unnecessary delays should be avoided. At the health policy level, novel strategies that reduce operative times and enhance the quality of perioperative care should be considered.[20,97] Because a decrease in operative time may not only improve patient outcomes through a reduction in the risk of developing complications but can also result in cost savings, decreased operative times should be a universal goal for surgeons, hospitals, and policy-makers.[98,99] Future study is recommended on the evaluation of interventions targeted to reducing operating time.

Strengths and limitations

This systematic review has several strengths including the comprehensive literature search, inclusion of numerous observational studies, and the completion of quantitative meta-analysis and meta-regression techniques to quantify the association between operative time and complications across, and within, various surgical specialties. The findings of this systematic review, however, should be interpreted in the context of the following limitations. First, there were many retrospective studies included. It is well-established that retrospective studies vary in quality based on the accuracy, completeness, and type of available data. In many cases, retrospective studies were constructed from surveillance databases. As such, the inclusion of confounding variables was limited in some instances. For example, many databases did not provide granular information on surgeon-specific characteristics (e.g., level of expertise). However, the surveillance databases (e.g., the ACS National Surgical Quality

Improvement Program) were often large, national, and employed robust and validated reporting systems that aimed to provide reliable and unbiased data regarding surgical risk factors and outcomes. Furthermore, despite study design differences, the study results were largely congruent between prospective and retrospective studies. Second, owing to the large volume of studies included in the review, study quality was not formally assessed. However, the sample size of included studies was large (i.e., 62% of the included studies had a sample size of ≥500 patients) and several studies adjusted their analyses for some important confounding variables to obtain more reliable estimates. Third, when the data were pooled for specific surgical specialties, several pooled analyses yielded high heterogeneity ($I^2 \geq 75\%$), which may have been due to factors such as smaller number of studies within a specific specialty and variability in study populations. As such, a random-effects model, which accommodates for heterogeneity and provides conservative estimates (i.e., less likely to find a false association), was used. As has been noted by previous research, significant heterogeneity can make results difficult to interpret.[100] Consequently, we draw cautious conclusions regarding the association between operative duration and complications within surgical specialties, especially when there is high heterogeneity. Fourth, although we presented ranges of study-reported average operative times within each specialty, these may not be representative due to the limited number of studies that reported on this measure. As well, the definition of operative time was either not provided or varied between studies (e.g., total surgical time *versus* total period of time from when the patient enters the operating room until the patient leaves the operating room). Fifth, all different types of complications were combined to capture an overall rate and conduct an overarching systematic review. It can be argued that certain complications are more clinically relevant, are more likely to be impacted by operative duration, and are more likely to be avoided through adjustments to modifiable factors influencing operative duration. Although a narrow focus on specific complications would permit a detailed exploration of individual trends and magnitudes, assessment of a large variety of complications allowed for a broader collection of studies, greater statistical power, and assessment of wide-ranging trends that are applicable to various surgical specialties.

Conclusions

To our knowledge, this is the first systematic review that quantitatively addresses the association between operative duration and a variety of complications across a diverse range of surgical specialties. Results showed that the likelihood of complications increases significantly with prolonged operative duration, approximately doubling with operative time thresholds exceeding 2 or more hours. Meta-analyses further showed that the likelihood of complications increases progressively with increasing increments of operative time. Although complication rates differed across surgical specialties, longer operative times correlated with a greater risk of complications for most surgical specialties when stratified by surgical type. Given the adverse consequences of surgical complications on patient outcomes and health care costs, surgeons, hospitals, and policy-makers should emphasize reduction in operative time through strategies that improve operative efficiency and optimize work flow. However, emphasis on reducing operative time should not be independent of additional considerations such as patient safety and other risk factors for complications. Future study is recommended on the evaluation of interventions targeted to reducing operating time.

Acknowledgments

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Disclosure

H.C., J.W.C., B.P-H.C., and P.H. are employees of Ethicon, Inc. B.S., N.C.F., and C.G.C. are employees of Cornerstone Research Group, under contract with Ethicon, Inc.

Supplementary Data

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