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The COMPARE Study: Comparing perioperative outcomes of Oncologic Minimally invasive laparoscopic, da Vinci robotic, and open Procedures: A systematic Review and meta-analysis of the Evidence

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Running Head: Review of robotic surgery for oncology

ABSTRACT

*Objective***:** To assess 30-day outcomes of *da Vinci* robotic-assisted (dV-RAS) versus laparoscopic/thoracoscopic (lap/VATS) or open oncologic surgery.

Summary Background Data: Complex procedures in deep/narrow spaces especially benefit from dV-RAS. Prior procedure-specific comparisons are not generalizable.

Methods: PubMed, Scopus and EMBASE were systematically searched (latest: 11/17/2023) following PRISMA and PROSPERO (Reg#CRD42023466759). Randomized, prospective, and database studies were pooled as odds ratios (OR) or mean differences (MD) in R using fixed-effect or random-effects (heterogeneity significant). ROBINS-I/RoB 2 were used to assess bias.

Results: Of 56,314 unique references over 12 years from 22 countries, 230 studies (34 randomized, 74 prospective, 122 database) comparing dV-RAS to lap/VATS or open surgery across 7 procedures, 4 specialties, representing 1,194,559 dV-RAS; 1,095,936 lap/VATS and 1,625,320 open cases were included. Operative time for dV-RAS was longer than lap/VATS (MD:17.73min [9.80,25.67], p<0.01) and open surgery (MD:40.92min [28.83,53.00], p<0.01), whereas hospital stay was shorter (lap/VATS MD:-0.51d [-0.64,-0.38], p<0.01; open MD:-1.85d [-2.09,-1.62], p<0.01) and blood loss was less versus open (MD:-293.44ml [-359.53,-227.35]). There were fewer dV-RAS conversions (OR:0.44 [0.40,0.49], p<0.01), transfusions (OR:0.79 [0.72,0.88], p<0.01), postoperative complications (OR:0.90 [0.84,0.96], p<0.01), readmissions (OR:0.91 [0.83,0.99], p=0.04), and deaths (OR:0.86 [0.81,0.92], p<0.01) versus lap/VATS, and fewer transfusions (OR:0.25 [0.21,0.30], p<0.01), postoperative complications (OR:0.56 [0.52,0.61], p<0.01), readmissions (OR:0.71 [0.63,0.81], p<0.01), reoperations (OR:0.89 [0.81,0.97], p<0.01), and deaths (OR:0.54 [0.47,0.63], p<0.01) versus open surgery. Blood loss (MD:-12.26mL [-29.44,4.91], p=0.16) and reoperations (OR:1.03 [0.95,1.11], p=0.48) were similar for dV-RAS and lap/VATS. There was significant heterogeneity.

Conclusions: Da Vinci-RAS confers benefits across oncological procedures and study designs. These results provide clinical evidence to multi-specialty-care decision-makers considering dV-RAS.

INTRODUCTION

Minimally invasive surgery (MIS) has transformed the surgical management of disease. Compared to open surgery, traditional MIS (endoscopy, laparoscopy, video-assisted thoracoscopy) offers a number of benefits including smaller incisions, less morbidity, faster recovery, reduced pain, shorter length of hospital stay, and improved cosmesis.[1-5] However, it has several technical limitations, most notably lower quality vision and depth perception from two dimensional (2D) imaging, camera instability from a hand-held design, limited range motion and dexterity from straight and rigid hand-held instruments capable of only 4-degrees of movement, a propensity for surgeon fatigue, work-related musculoskeletal injuries and tremor from physically demanding ergonomics, and a steep learning curve.[6-8] (The *da Vinci*® robotic-assisted surgery system (Intuitive Surgical Inc., Sunnyvale, CA) received U.S Food and Drug Administration approval in 2000 and advanced MIS by overcoming many of the technical limitations.[6,9] Collectively, *da Vinci's* technological advancements facilitated accuracy and precision of MIS dissection and reconstruction, most appreciably within deep, limited or narrow cavities such as the chest, abdomen, and pelvis and enabled the expansion of MIS into more highly complex surgical procedures compared to traditional minimally invasive approaches.[6,10-12]

There is an abundance of research comparing perioperative outcomes between dV-RAS, traditional MIS (lap/VATS) and open surgery for individual surgical procedures.[13-17] These studies generate procedure-specific evaluations of robotic-assisted surgery. Few studies encompass a more comprehensive evaluation of robotic-assisted surgery by comparing perioperative outcomes by surgical approach across multiple surgical procedures.[18-23] Thus far, the meta-analyses[18,19,21-23] comparing perioperative outcomes by surgical approach across procedures have been subject to the following limitations: (1) restricted study design eligibility

to randomized controlled trials (RCTs)[18,19,21,22] despite limited numbers of RCTs and the majority of existing RCTs exhibiting small sample sizes (<30 patients per arm),[18,23] (2) pooled analysis comparisons of perioperative outcomes between robotic-assisted surgery and laparoscopic surgery only (due to inadequate numbers of robotic-assisted versus open surgery publications or limited scope),[18,21,22] (3) a lack of a common set of clinical outcomes across prospective studies, (4) evaluation of an extensive range of surgical procedures and complexities such as, but not limited to, combining benign and oncologic surgical indications,[18,19,22,23] and (5) limited reporting of important perioperative outcomes including conversions, 30-day mortality, 30-day readmissions and 30-day reoperations.

The current systematic review and meta-analysis addresses these limitations by including RCTs as well as expanding study design eligibility to enable the use of real-world data derived from prospective cohort and large databases studies published within the last twelve years (2010-2022), increasing the number of perioperative outcomes for pooled comparisons between dV-RAS and laparoscopic surgery and dV-RAS versus open surgery, and focusing on studies of complex oncologic surgery commonly performed in the deep, limited and narrow spaces of the thoracic (lobectomy), abdominal (hysterectomy, colectomy, and partial nephrectomy) and pelvic (prostatectomy, low anterior resection/total mesorectal resection/intersphincteric resection, LAR/TME/ISR) cavities. The aim of this meta-analysis was to determine if oncologic surgery performed with the *da Vinci* robotic-assisted surgical system was associated with improvements in 30-day perioperative outcomes compared to lap/VATS or open surgery.

METHODS

This systematic review and meta-analysis was performed and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines[24] (Supplementary Tables 1 and 2, Supplemental Digital Content 1, http://links.lww.com/SLA/F333) and is registered in PROSPERO international prospective register of systematic reviews (CRD42023466759). The protocol is available upon request. Separate searches were performed for each procedure in PubMed, Embase and Scopus (last searched on November 17, 2023) for papers published between January 1, 2010 to Dec 31, 2022. Search strategies included combinations of robotic keywords: "*da Vinci*", "robot*", "minimally invasive", procedure-specific terms: "lobectomy", "hysterectomy", "prostatectomy", "nephrectomy", "colectomy", low anterior resection", "mesorectal" and cancer terms: "carcinoma", "malignancy", "oncologic". The complete search terms used for each database are listed in Supplementary Tables 3,4, Supplemental Digital Content 1, http://links.lww.com/SLA/F333 for right colectomy and partial nephrectomy, and remaining procedures were referenced elsewhere[25]. Two researchers screened each reference and checked the papers for relevancy. The full text of relevant studies was evaluated for eligibility based on inclusion and exclusion criteria. Finally, data from the lists of eligible publications was manually extracted. The extracted data was quality control checked by two researchers in its entirety.

Inclusion criteria consisted of: (1) a study reporting on at least one primary, non-metastatic, oncologic surgery performed with the *da Vinci*® robotic-assisted surgical system within the chest, abdominal and pelvic cavities, including lung lobectomy, total or radical hysterectomy, partial nephrectomy, right colectomy, radical prostatectomy, or LAR/TME/ISR, (2) a peer-reviewed manuscript published between January 1, 2010 and December 31, 2022 (to include the

widespread use of the da Vinci Si and Xi systems, the clearance by the FDA of multiple procedures, and the expansion of robotic use to more than just pioneer surgeons) and (3) a study design inclusive of randomized controlled trials, database studies, and prospective studies comparing dV-RAS with laparoscopic/VATS or open surgery.

Exclusion criteria included: (1) a non-English language publication, (2) a pediatric study population, (3) a non-peer reviewed health technology assessment publication, (4) a study of an alternate surgical technique or approach (e.g. transanal surgery, single-portal surgery, hand-assist surgery), (5) a study with no stratified analysis by study arm (e.g. combined results from dV-RAS, lap/VATS or open cohorts), (6) a study reported only combined data from multiple procedures or indications (i.e. inclusion of procedures and indications beyond the scope of the procedures included in this study), (7) the study did not report any 30-day perioperative clinical outcomes of interest, and (8) the study included a redundant patient population and similar conclusions. The 30-day perioperative outcomes of interest included: conversions to open surgery, operative time, blood transfusions, estimated blood loss, length of hospital stay, 30-day complications, 30-day readmissions, 30-day reoperations and 30-day mortality. Data extraction was performed using a standardized data collection form. The first author's name, publication year, study type, sample size, country of origin, database used, and the outcomes of interest were extracted from each study. Data were then standardized to mean and standard deviation (continuous outcomes) and event n and total n for binary outcomes. Studies reporting outcomes of interest in a way that could not be standardized and pooled with the other papers were included in the review, but not in the meta-analysis, with the specific reasons reported in the flowchart. Quality assessment was performed by two reviewers (AY, NP). Disagreements were adjudicated by discussion and consensus between reviewers. Meta-analyses were conducted

using R Software[26], forest plots for each outcome and comparison were created and summarized into main forest plots showing results by procedure. Analyses were performed separately for dV-RAS versus lap/VATS and dV-RAS versus open surgery. The measure of effect for each perioperative outcome pooled across 7 oncologic procedures was analyzed either as an odds ratio (OR) or risk difference (RD) with 95% confidence interval [95% CI] for a binary outcomes (conversions, blood transfusions, 30-day complications, 30-day readmissions, 30-day reoperations and 30-day mortality) or as a weighted mean difference (MD) with 95% CI for a continuous outcomes (operative time, blood loss, length of hospital stay). A risk difference was also calculated in instances where an odds ratio could not be calculated for studies in an analysis due to zero event rates in both comparison cohorts. A fixed-effect model was used when heterogeneity was not statistically significant (Chi^2 $p \geq 0.05$ or I^2 <50%) while a random-effects model was used otherwise. Individual studies were weighted in the pooled analysis based on a combination of the study sample size and the variability of the outcome of interest. This weighting was also used to calculate means, standard deviations, proportions, and 95% confidence intervals. A 2-tailed value of $p<0.05$ was considered statistically significant. Subgroup analysis was performed by study type. Bias was assessed using the Cochrane Risk of Bias (ROBINS-I and RoB 2) tools by two reviewers for randomized and non-randomized studies and publication bias was assessed using visual analysis of funnel plots. Data collection forms, extracted data, forest plots showing individual studies, and the R code utilized are available upon request.

RESULTS

A total of 56,314 unique references were screened, with 230 publications comparing dV-RAS to lap/VATS and open surgery that meet inclusion criteria and were included in the meta-analysis.

These publications included 7 oncologic surgeries within 4 surgical specialties and covered 12 years of peer-reviewed published work from over 22 countries globally. They include 34 RCTs, 74 prospective studies and 122 database studies representing 1,194,559 dV-RAS; 1,095,936 lap/VATS and 1,625,320 open cases (Figure 1 and Supplementary Figures 1-6, Supplemental Digital Content 1, http://links.lww.com/SLA/F333, Bibliography of included studies in Appendix A, Supplemental Digital Content 1, http://links.lww.com/SLA/F333). There were 84 papers that compared dV-RAS to Lap/VATS, 71 papers that compared dV-RAS to open surgery, and 75 papers that compared all three surgical approaches. Year of publication for the various comparison types is shown in Supplementary Table 5, Supplemental Digital Content 1, http://links.lww.com/SLA/F333 and show no different in the distribution of publications by year for the three comparison paper types (Chi^2, p=0.2374), or for publications with a laparoscopic cohort versus dV-RAS/Open comparison papers (Chi^2, p=0.052). Median year of publication was also calculated and was 2019 for comparisons including a Lap/VATS cohort, and 2017 for dV-RAS versus open papers. Papers included in the review, but not the meta-analysis are listed at the end of each procedure in Appendix A, Supplemental Digital Content 1, http://links.lww.com/SLA/F333, are listed in the flowcharts (Supplementary Figures 1-6, Supplemental Digital Content 1, http://links.lww.com/SLA/F333), and Supplementary Table 12, Supplemental Digital Content 1, http://links.lww.com/SLA/F333 reports the data as it was presented in the paper.

Study characteristics by procedure type are provided in Supplementary Tables 6-11, Supplemental Digital Content 1, http://links.lww.com/SLA/F333. These include the type of study (RCT, Database, Prospective), the time period when data was collected, the sample size of each comparative cohort, the outcomes that were reported and analyzed and a summary of the Risk of

Bias assessments based on either the ROBINS-I or RoB-2 tools depending on the type of study. In general, there was higher risk of bias among database and prospective studies, especially in the domains of potential confounding and selection. RCTs had lower overall risk of bias in general, with bias mainly arising from domains pertaining to the randomization process or deviations from intended interventions. The overall results of the meta-analysis pooled across procedures, comparing dV-RAS versus lap/VATS and dV-RAS versus open surgery are provided for the 9 clinical outcomes of interest in Table 1 and Supplementary Figures 7-23, Supplemental Digital Content 1, http://links.lww.com/SLA/F333. Summary forest plots for the each of the outcomes by cohort comparisons are provided in Figures 2-4, with any procedure-subgroup specific risk difference calculations reported in the footnotes for comparison.

Operative time was longer by 17.7 minutes for dV-RAS in comparison to lap/VATS and by 40.9 minutes in comparison to open surgery, both results were statistically significant $p<0.01$ and $p<0.01$ respectively. dV-RAS cases were 56% less likely to convert to open surgery compared to lap/VATS cases (OR:0.44 [0.40 0.49], $p<0.01$). There was a statistically significant difference in estimated blood loss between dV-RAS and open cases by 293.44 ml ($p<0.01$), with no difference seen relative to lap/VATS ($p=0.16$). There was a significant difference when comparing the likelihood of receiving a blood transfusion: dV-RAS cases were 21% less likely to receive a blood transfusion versus lap/VATS counterparts (OR:0.79 [0.72, 0.88], $p<0.01$) and were 75% less likely to be transfused relative to those undergoing open surgery (OR:0.25 [0.21, 0.30], $p<0.01$). dV-RAS cases were 10% less likely to experience a postoperative complication within 30 days versus the lap/VATS cohort (OR:0.90 [0.84, 0.96], $p<0.01$) and 44% less likely compared to those undergoing open surgery (OR:0.56 [0.52, 0.61], $p<0.01$). Cases in the dV-RAS group resulted in a half a day savings in hospital stay when compared to lap/VATS cases

and 1.85 days hospital stay savings in comparison to open cases, ($p<0.01$, $p<0.01$). Readmissions within 30 days of surgery were less likely to occur after dV-RAS when compared to lap/VATS (OR:0.91 [0.83, 0.99], p=0.04), and open surgery (OR:0.71 [0.63, 0.81], $p<0.01$). Patients undergoing dV-RAS and lap/VATS were just as likely to be reoperated within 30 days of surgery, however when compared to open cases, dV-RAS resulted in an 11% lower likelihood of reoperation (OR:0.89 [0.81, 0.97], $p<0.01$). Mortality within 30-days of surgery was significantly lower after dV-RAS: relative to lap/VATS (OR:0.86 [0.81, 0.92], $p<0.01$) and open surgery (OR:0.54 [0.47, 0.63], $p<0.01$). Funnel plots are provided in Supplementary Figure 24, Supplemental Digital Content 1, http://links.lww.com/SLA/F333.

Subgroup analysis: dV-RAS versus lap/VATS:

A stratified analysis of each clinical outcome by study type was conducted to understand the impact of study design; RCT, Database or Prospective on each outcome (see Tables 2 and 3). When comparing dV-RAS and lap/VATS, operative time was significantly longer by an average 26.8 mins and 28.9 mins according to RCT and Database studies; however, no difference was seen among prospective studies. Conversions to open surgery was statistically significant in favor of dV-RAS regardless of study design. There was no difference in blood loss between dV-RAS and lap/VATS regardless of study design; however, dV-RAS cases remained less likely to receive a blood transfusion for database studies only. Length of stay was on average half a day shorter for dV-RAS cases and remained consistent regardless of study design. Postoperative complications were 9-23% less likely to occur among dV-RAS cases in comparison to lap/VATS and were significantly different across all 3 study designs. Readmissions and mortality within 30-days of surgery were comparable between dV-RAS and lap/VATS except among database

studies (OR:0.90, [0.82, 0.99], p=0.03; OR: 0.84 [0.74, 0.96], p<0.01) respectively, whilst 30-day reoperations were still comparable between dV-RAS and lap/VATS for all study types.

Subgroup analysis: dV-RAS versus open surgery:

Table 3 shows that operative time was on average between 35.8 to 42.9 minutes longer for dV-RAS versus open cases across all study types and was statistically significant. Estimated blood loss and the need for blood transfusions was consistently lower for dV-RAS irrespective of study type with the exception of transfusion rates among RCTs, that while trending lower, did not reach statistical significance. Postoperative complications within 30-days of surgery were 30-44% less likely to occur and statistically significant in favor of dV-RAS as was length of hospital stay which was on average between 1.6 and 2.1 days shorter for dV-RAS cases across the 3 study designs. Results for readmissions and reoperations were mixed across study types. Among database studies, a lower likelihood of readmissions and reoperations within 30-days for dV-RAS was demonstrated; 28% and 10% respectively. Further, prospective studies showed significantly lower likelihood of 30-day reoperations for dV-RAS. Mortality within 30-days was comparable between dV-RAS and open surgery for RCT and Prospective studies and showed a 45% lower likelihood and significant difference for database studies only.

DISCUSSION

This study evaluated dV-RAS, lap/VATS and open surgery across 7 oncologic surgical procedures by summarizing 30-day perioperative outcomes. The results of this meta-analysis demonstrate the advantages of dV-RAS surgery for oncologic procedures, including a lower risk of conversions, blood transfusions, length of hospital stay, 30-day complications, readmissions,

and mortality in comparison to lap/VATS. Advantages of dV-RAS in comparison to open surgery were seen for all outcomes studied.

Operative Time:

The current meta-analysis demonstrated a longer operative time between dV-RAS compared to lap/VATS and open surgery across the 7 surgical procedures. Prior multispecialty meta-analyses[18,22,23] reported longer operative times (pooled mean differences ranging from 11.48 minutes[22] to 27.24 minutes longer[18]) for dV-RAS compared to laparoscopic surgery. Tan's et al. (2016)[23] meta-analysis calculated a pooled ratio of means (a unit less measure) for operative time and found robotic-assisted surgery increased operative time by 7.3% compared to open surgery. The current study's finding of increased operating time between dV-RAS and laparoscopy of 17.7 minutes may represent progressive improvements in dV-RAS experience and expertise[26,27] and surgical team familiarity and efficiency with the *da Vinci* robotic platform (e.g. draping, positioning and docking).[28-30] It is not unusual for conventional MIS (laparoscopic/VATS) to have longer operative times when compared to open surgery, particularly for lobectomy,[31] rectal surgery,[32] colectomy,[33] prostatectomy[34] and partial nephrectomy.[35] Consequently, the longer operative time compared to open surgery may be more of a function of the minimally invasive surgical approach to oncologic surgery in general and less of a function of the robotic approach specifically. More importantly, the longer dV-RAS operative time did not translate into compromised clinical outcomes (e.g. greater conversions, blood transfusions, length of hospital stay, 30-day complications, readmissions or reoperations).

Conversions:

The dV-RAS group had a 56% lower risk of conversion to laparotomy compared to lap/VATS, which is one of the most consistent findings, with each procedure and each study type independently significant. An earlier meta-analysis of RCTs by Roh and colleagues[22] that included benign and cancer procedures, reported no difference in conversions between robotic-assisted and laparoscopic surgery. However, the authors also included conversions to laparoscopy, which were often due to issues unrelated to the surgery and more to do with inexperience with the robotic system. An analysis of the same papers (excluding the AESOP paper that was not robotic) looking at just conversions to laparotomy, results in a significantly lower conversion rate for robotic surgery (3/541 (0.6%) versus 22/544 (4.0%); OR: 0.22 [0.09, 0.54], p<0.01; heterogeneity I^2=0%, Chi^2 p=0.72; RD: -0.04 [-0.06, -0.01], p<0.01 ; heterogeneity I^2=19%, Chi^2 p=0.22) showing consistency with our findings. The conversion to laparotomy rate is a measure of the surgical effectiveness of a minimally invasive procedure and is clinically significant because it is typically associated with increased blood loss, higher rates of intraoperative and postoperative complications, longer hospital stays, increased healthcare costs[36-39] and ultimately denies the patient the benefits of minimally invasive surgery. The cost paper by Cleary et al 2018[37] reported an adjusted episode payment savings of $2,580 for patients avoiding a conversion, which would translate into a savings of $152,220 per 1,000 patients using the overall estimate for conversions from our meta-analysis (5.7% dV-RAS vs. 11.6% Lap/VATS) and a savings of $95,460 per 1,000 patients using the RCT subgroup analysis estimate (4.9% dV-RAS vs. 8.6% Lap/VATS).

Estimate Blood Loss / Blood Transfusions:

The dV-RAS blood transfusion risk was 21% lower compared to traditional lap/VATS and was 75% lower compared to open surgery. These findings are consistent with Tan's et al[23] pooled analysis of RCT and prospective non-randomized studies (1998-2014) comparing transfusions for robotic-assisted surgery and MIS (13 studies) or open (17 studies) surgery but differ from Roh's et al.[22] meta-analysis who reported no difference in transfusion rate between robotic-assisted surgery and laparoscopic surgery in an analysis of 4 RCTs. This is most likely because their sample size was too small to detect the difference versus conventional laparoscopy. Our main analysis of transfusions included 49 studies; our study type subgroup analysis showed significance only in the database study group, even though all study types had a lower transfusion rate in the robotic group. The larger difference was in the comparison to open surgery, which is where the benefit of robotic surgery would make the most clinical difference. Excessive perioperative blood loss is a major surgical complication that is often managed with blood transfusion and in some instances re-operation.[40] Intraoperatively, bleeding hampers surgeon visibility, agility and precision within the operative field.[41] A 2014 American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database analysis found perioperative blood transfusion to be independently associated with an increased risk of morbidity and mortality after most major abdominal operations.[42] Additionally, surgical patients who experienced a bleeding related complication and/or received a blood transfusion had a longer stay in the intensive care unit (overall mean: 3.3 days vs. 0.5 days), overall hospital stay (overall mean: 10.4 days vs. 4.4 days), resulting in higher mean inpatient costs than patients who did not have a bleeding complication or blood transfusion (by $13,210 for solid organ surgery).[40] The blood transfusion estimate for robotic (3.6%) vs. open (11.2%) result in a 7.6% difference, which would translate into a robotic cost savings of $1,003,960 for every 1,000 solid organ

surgery patients. This is consistent with a 2010 prospective study from two American and two European hospitals that reported annual costs for blood and transfusion-related activities (e.g. staff time, supplies, direct and indirect overhead costs) in surgical patients ranged between $1.62 to $6.03 million per hospital.[43]

30-day Postoperative Complications:

The dV-RAS 30-day complication risk was 10% less compared to lap/VATS and 44% less compared to those undergoing open surgery. This finding is consistent with the robotic versus open analysis of 30-day overall complications (11.6% (515/4453) all robot types vs. 21.4% (693/3245) open) in the Tan 2016[23] meta-analysis, but is in contrast to other robotic vs. laparoscopic meta-analyses that reported comparable 30-day overall complications,[23] total complications,[18] intraoperative complications,[22] postoperative complications[22] or greater total complications.[22] This is most likely due to the inclusion of benign procedures and a smaller sample size in these other studies. It is well documented that postoperative complications increase healthcare costs,[44-46] and healthcare expenditures increase with postoperative complication severity.[47] A National Inpatient Sample database study of patients who underwent major gastrointestinal resections for malignancy between 2001 and 2014 reported any in-hospital complication increased index hospital costs by an average of $20,900 (95% CI: $20,300-21,500).[48] This would translate into a savings of $1,525,700 for dV-RAS versus open surgery based on 30-day postoperative complication rates of 17.9% dV-RAS, 25.2% open (see Table 1). Additionally, patients who had a complication stayed in hospital an average of 5.5 days longer, were three times more likely to require a non-routine discharge and at six times higher risk of in-hospital death compared to patients who did not have a complication.[48] For the patient, postoperative complications are also associated with reduced quality of life and decreased

satisfaction with their surgical and postoperative experience.[49] Postoperative complication rates are indicators of surgical and hospital quality. Therefore, implementation of interventions associated with reduced complications, such as dV-RAS, may provide greater value-based care to both patients and hospitals.

Length of Hospital Stay:

The hospital stay for the dV-RAS group was on average half a day shorter compared to lap/VATS and almost 2 days shorter than open surgery, a finding that was seen consistently across all procedures and all study types. Differences in discharge protocols can confound comparisons in hospital stay; however, RCT and prospective studies specifically control for these types of differences. In addition, systematic differences in discharge criteria (such as for US versus non-US institutions) do not affect a pooled mean difference *per se* because the difference should influence hospital stay for both the robotic and comparator cohorts relatively equally within an institution. For example, if a European hospital requires patients to be off of a catheter following prostatectomy surgery before discharging that patient, it would require both robotic patients and laparoscopic patients to be catheter free.

Previously published meta-analyses found no difference in length of hospital stay between robotic-assisted and laparoscopic surgery across surgical procedures.[18,22,23] The Broholm 2016[18] RCT meta hospital stay analysis included 70% benign studies (only 3 cancer papers) and the majority of studies were published before 2010, with only 1 paper overlap with our study[50]. The Roh 2018[22] RCT meta also included benign and cancer studies mixed in the analysis, and limiting their analysis to cancer papers would also result in a shorter hospital stay for the robotic group (MD: -1.04 [-1.32, -0.76], $p<0.00001$, $I^2=46\%$, Chi^2 $p=0.08$ fixed model). Tan 2016[23] also

mixed benign and cancer procedures in the hospital stay analysis and included studies published before 2010. However, a more recent meta-analysis by Choi et al. 2024 also found significantly shorter hospital stay with dV-RAS compared to traditional laparoscopy.[19] This meta did mix benign and cancer papers, which may be why they found a shorter difference of a quarter of a day. Tan et al. reported a shorter hospital stay for robotic-assisted surgery compared to open surgery across surgical procedures.[23] Length of hospital stay is an indicator of hospital efficiency[51] and quality of care.[52] Hospitals with the shortest length of stays for common surgical procedures have lower costs, fewer postoperative complications, higher surgical volumes and greater use of MIS.[52] Prior research has shown that shorter hospitals stays are not associated with increased post-discharge care spending (i.e. no increased payments for readmissions or physician services) for older adults undergoing major surgery[52]. Given that in 2018, inpatient care in the United States averaged $2,517 per day[53,54] even modest improvements in length of hospital stay, such as a half of a day, can translate into large healthcare cost savings. Assuming a single surgeon annual case volume of 200 procedures, a half day shorter hospital stay would translate into a savings of $251,700 and a 1.8 day shorter hospital stay (robotic vs. open surgery) would save $906,120.

30-day Readmissions, Reoperations, and Mortality:

An ACS NSQIP study found surgery-related complications were the most common reason for 30-day unplanned readmissions in surgical patients. The 3 leading causes of readmission were surgical site infection, ileus or obstruction and bleeding.[55] Additionally, although experiencing an inpatient complication was related to an unplanned hospital readmission, most readmissions were attributable to a new surgery-related complication.[55] Ejaz et al. (2016)[44] reported that a 30-day readmission after a major abdominal surgery increased the total index

hospitalization costs by $4,991 for all patients (readmission: $29,312 vs no readmission: $24,321; p<0.001) and by $4,337 for patients who did not have an inpatient complication (readmission: $26,799 vs no readmission: $22,462; p< 0.001). Regardless of reason, healthcare costs are increased when surgical patients require readmissions. Although absent from prior multispecialty meta-analyses,[18,22,23] the current study evaluated readmissions, reoperations, and mortality within 30-days of surgery. Readmissions and mortality were both lower in the dV-RAS group versus both lap/VATS and versus open surgery, whereas reoperations were only different versus open surgery. These 30-day outcomes are meaningful, as approximately 25% of postoperative deaths occur after hospital discharge,[56] while readmissions are associated with increased risk of postoperative mortality in high-risk surgical patients (e.g. colectomy, lobectomy),[57] and prolonged physical functional recovery in older surgical patients.[58] Furthermore, this demonstrates that dV-RAS shorter length of stay did not translate into greater rates of hospital readmission or postoperative mortality.

Limitations:

A first limitation of this meta-analysis may be the potential bias from the inclusion of studies with non-randomized prospective and database study designs. To account for this potential bias, subgroup analyses were performed to assess the effect of study design on the summary effect size of perioperative outcomes[59], including an analysis limited to RCTs. The benefits of decreased hospital stay, fewer conversions, and fewer 30-day postoperative complications for dV-RAS versus conventional laparoscopy were seen across all study types, including in the RCT subgroup analysis, demonstrating the robustness of these results. RCTs are traditionally used in meta-analyses as they minimize bias; however, bias is also present in surgical RCTs because of the impracticality of standardizing surgical technique, different surgeons performing robotic,

laparoscopic, and open surgery, often with differing experience levels, and the lack of ability to blind surgeons, patients, or nurses providing care and assessing outcomes. RCTs also suffer from limitations relating to small sample size, which limits the ability to detect differences with rare events and often results in outcomes that could change in significance with the addition of more patients.[60] Furthermore, the surgical literature contains relatively few RCTs due to the inherent difficulties and expenses of conducting surgical trials. Although potential biases are likely to be greater for non-randomized studies, they can complement the limited surgical RCT literature by providing context and generalizability in assessing the effectiveness of surgical approaches with real-world surgeon and patient populations that are larger and more diverse.[61] Second, perioperative outcomes were aggregated despite differences in operational definitions. In studies, perioperative outcomes were frequently stated, but were less frequently defined and when defined, the terminology was consistent within a study but often differed across studies (e.g. operative time, total operative time, skin-to-skin, wheels-in-to-wheels-out) complicating the aggregation of outcomes by each definition. In an attempt to make use of available data, this meta-analysis did not discern between intra-study differences in perioperative outcome definitions. While recognizing that this methodological decision may introduce variability, the inclusion of only comparative studies ensures that the perioperative definition inconsistency would be similarly inconsistent across surgical cohorts. Forth, significant heterogeneity was observed for the majority of outcomes in the main analysis, most likely due to study type and procedure differences resulting in differences in effect sizes between studies.[59] The subgroup analysis by study type showed less heterogeneity within a study type; however, there can still be differences between studies due to procedure characteristics (such as type and severity of disease and differences in extent of resection), surgeon characteristics such as experience level, and

patient characteristics. When heterogeneity was present, a random-effects model was used and may have contributed to lower confidence in the summary estimates. Fifth, the results of this COMPARE study are applicable to the 7 included oncologic surgical procedures and to perioperative outcomes and may not be generalizable to all procedures or to oncological outcomes, as that was not the focus of this paper. The procedures were chosen as representative of complex and commonly performed *da Vinci* surgeries and the outcomes chosen represent safety and effectiveness measures. A separate meta-analysis of long-term oncological outcomes for 5 of the 7 procedures in this study was recently published by Leitao et al.[25] demonstrating similar or improved oncologic outcomes for dV-RAS.

Future Directions

While this work focused on clinical outcomes from oncological procedures performed using the da Vinci Surgical System (all multiport models) compared to laparoscopy and open surgery, there have been advances in the area of robotic technology. Recently, the next generation da Vinci robotic system dV5 received clearance from the US FDA and now includes haptic feedback and ergonomic improvements to the surgeon console. In addition, numerous competitive platforms have been introduced to the global market. Adoption of these new devices in general surgery is constantly growing with the extension of regulatory approvals. However, standardization of the training process and the assessment of skill transferability is still lacking.[62] Future studies will be required to better understand their clinical and economic benefits.

Conclusion

This meta-analysis covering twelve years of peer-reviewed literature across 7 oncologic surgeries, demonstrates multiple benefits for dV-RAS as compared to both lap/VATS and open

surgery. The strengths of this meta-analysis include the use of multiple study designs (RCTs, prospective, and real-world evidence), the evaluation of perioperative outcomes in several complex oncologic operations, and the expansion of the utility of the results to those interested in individual or collective procedures. The results of this study will be helpful to decision makers considering the use of robotics in a multi-specialty-care setting.

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Figure 1: Summary PRISMA Flowchart

Flowchart showing inclusion and exclusion of each paper for each procedure. *Low Anterior Resection (LAR) group also includes total mesorectal excision and intersphincteric resection. PSE=Pubmed, Scopus, Embase; refs=references; P&I=Procedure and Indication of Interest. For identification, searches in each database were created using a combination of robotic, (e.g. robot, robotic, robotically, “da Vinci”, “intuitive Surgical”), indication (e.g. cancerous, malignancy, etc), anatomical (e.g. prostate, renal, uterine), and procedure (e.g. nephrectomy, right colectomy) or specialty (renal, gynecology, urology) terms. For the screening step, articles including patients with primary, localized cancer that underwent one of the procedures of interest using da Vinci surgery were assessed. At the eligibility step, only studies published within the timeframe reporting primary clinical data (no reviews, comment, etc) and that compared da Vinci surgery to another surgical approach, with at least 20 patients in each arm were considered (no case series or case reports). Only randomized-controlled trials, prospective studies, and database studies were included. Included in review: English language studies reporting on an adult population, treated using standard surgical techniques (i.e. no transanal or single-port), with the data stratified by procedure, indication, and surgical approach for at least one outcome of interest (operative time, blood transfusions, estimated blood loss, conversions to open surgery, length of hospital stay, 30 day: postoperative complications, readmissions, reoperations, and mortality). Papers with redundant patient populations and similar conclusions were excluded. Included in meta-analysis: papers where mean and standard deviation could be extracted or calculated for continuous outcomes and event n and total n could be extracted or calculated for binary data such that data could be pooled were included in the meta-analysis. Adding across columns does not equal total number of unique papers; Shah 2022 Impact[63] is included in lung lobectomy, partial

nephrectomy, low anterior resection, and right colectomy. Detailed flowcharts for each procedure that show exclusion reasons can be found in Supplementary Figures 1-6. Details on papers that were included in the review in which data could not be pooled are listed in Supplementary Table 12, Supplemental Digital Content 1, http://links.lww.com/SLA/F333.

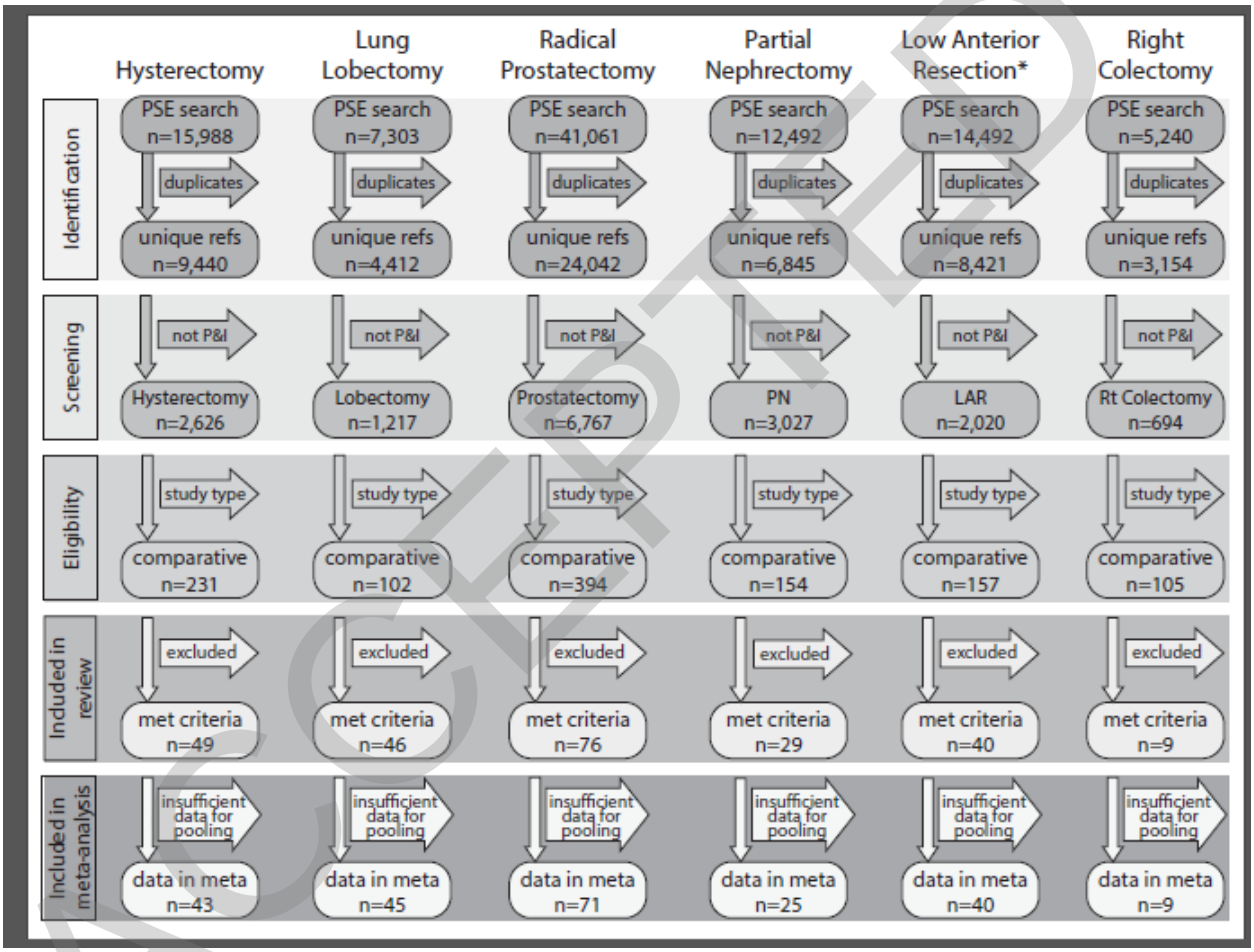

Figure 2:

Forest plots for A) conversions for dV-RAS vs. lap/VATS, B) operative time for dV-RAS vs. lap/VATS, c) operative time for dV-RAS vs. open surgery, D) blood loss for dV-RAS vs. lap/VATS, E) blood loss for dV-RAS vs. open surgery. Black squares visually represent the effect size and the black line represents the 95% confidence interval. The black diamond represents the overall pooled effect size and its horizontal size represents the 95% confidence interval. Abbreviations: dV-RAS=da Vinci robotic-assisted surgery, lap/VATS=traditional laparoscopic or video assisted thoracoscopic surgery, IV=inverse variance, CI=confidence interval, LAR/TME/ISR=low anterior resection/total mesorectal excistion/intersphincteric resection, df=degrees of freedom, RD=risk difference

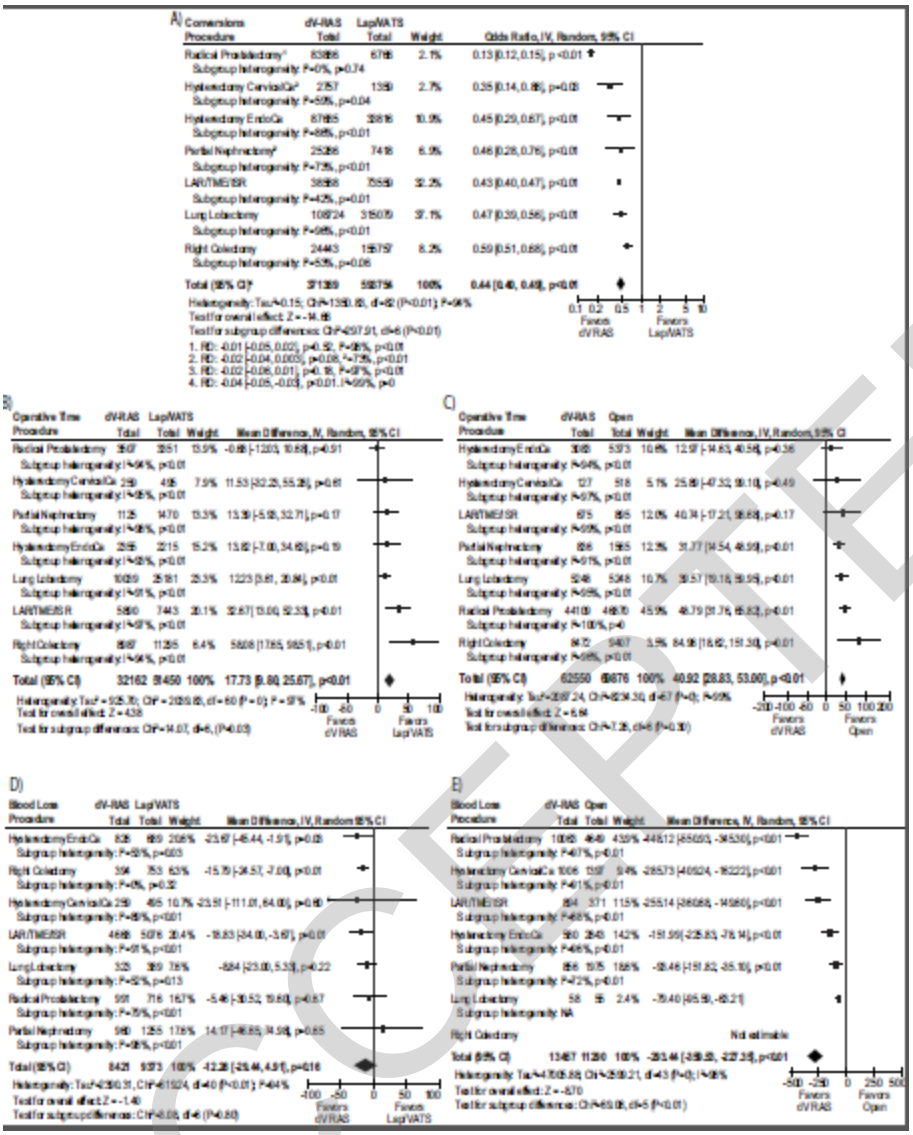
A)
Conversions
dV-RAS
LapVATS
Procedure
Total
Total
Weight
Odds Ratio, IV, Random, 95% CI
Radical Prostatectomy
Hysterectomy Cervical Ca
Hysterectomy Endo Ca
Partial Nephrectomy
LAR/TME/SR
Lung Lobectomy
Right Colectomy
Total (95% CI)
Favors dVRAS
Favors LapVATS
B)
Operative Time
dV-RAS
LapVATS
Mean Difference, IV, Random, 95% CI
C)
Operative Time
dV-RAS
Open
Mean Difference, IV, Random, 95% CI
D)
Blood Loss
dV-RAS
LapVATS
Mean Difference, IV, Random 95% CI
E)
Blood Loss
dV-RAS
Open
Mean Difference, IV, Random, 95% CI
Not estimable

Figure 3:

Forest plots for blood transfusions for A) dV-RAS vs. lap/VATS and B) for dV-RAS vs. open surgery, hospital stay for C) dV-RAS vs. lap/VATS and D) dV-RAS vs. open surgery, 30-day postoperative complications for E) dV-RAS vs. lap/VATS and F) dV-RAS vs. open surgery. Black squares visually represent the effect size and the black line represents the 95% confidence interval. The black diamond represents the overall pooled effect size and its horizontal size represents the 95% confidence interval. Abbreviations: dV-RAS=da Vinci robotic-assisted surgery, lap/VATS=traditional laparoscopic or video assisted thoracoscopic surgery, IV=inverse variance, CI=confidence interval, LAR/TME/ISR=low anterior resection/total mesorectal excistion/intersphincteric resection, df=degrees of freedom.

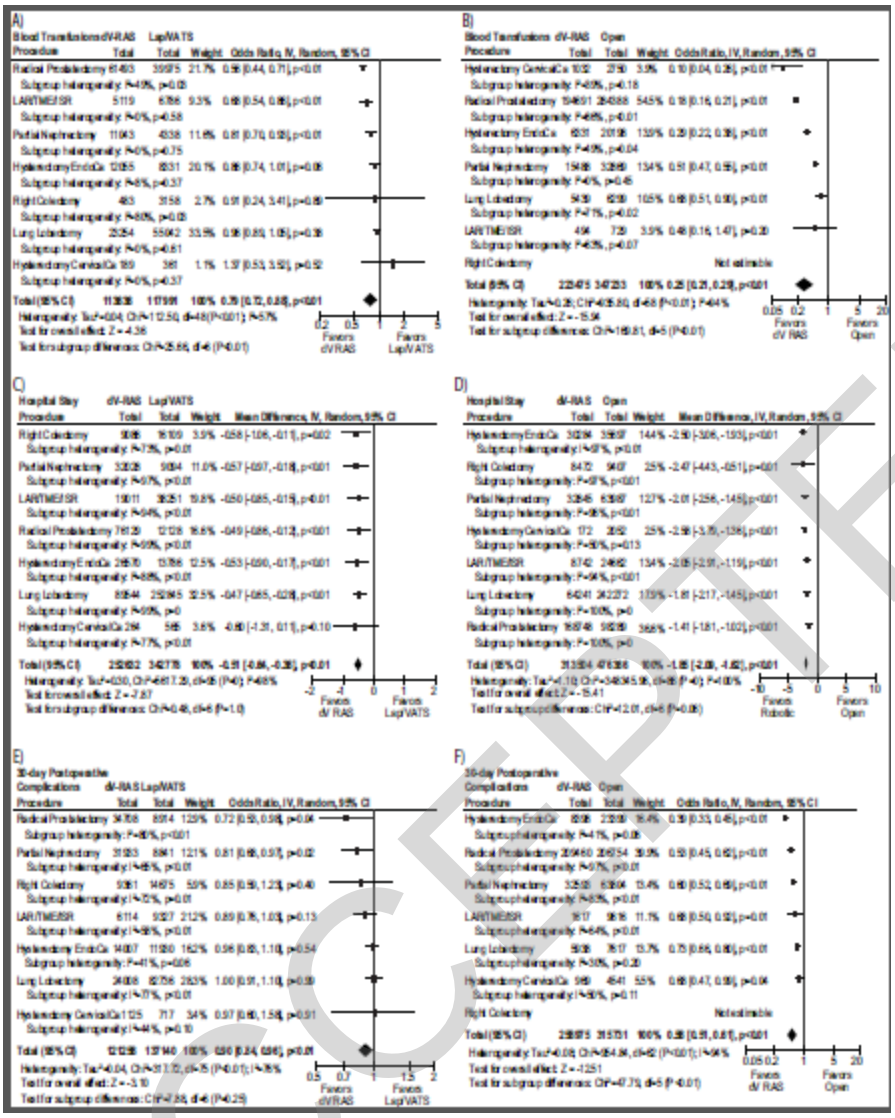
A)
Blood Transfusions dV-RAS LapVATS
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Radical Prostatectomy 61463 39975 21.7% 0.56 [0.44, 0.71], p<0.01
Subgroup heterogeneity: I²=49%, p=0.03
LAR/TME/SR 5119 6786 9.3% 0.69 [0.54, 0.88], p<0.01
Subgroup heterogeneity: I²=0%, p=0.58
Partial Nephrectomy 11063 4938 11.6% 0.81 [0.70, 0.93], p<0.01
Subgroup heterogeneity: I²=0%, p=0.75
Hysterectomy Endo/Ca 12655 6531 20.1% 0.88 [0.74, 1.01], p=0.06
Subgroup heterogeneity: I²=6%, p=0.37
Right Colectomy 483 3158 2.7% 0.91 [0.24, 3.41], p=0.89
Subgroup heterogeneity: I²=80%, p=0.03
Lung Lobectomy 25254 55902 33.5% 0.96 [0.89, 1.05], p=0.39
Subgroup heterogeneity: I²=0%, p=0.61
Hysterectomy Cervical/Ca 369 361 1.7% 1.37 [0.53, 3.52], p=0.52
Subgroup heterogeneity: I²=0%, p=0.37
Total (95% CI) 113338 117991 100% 0.78 [0.72, 0.84], p<0.01
Heterogeneity: Tau²=0.04; Chi²=112.50, df=48 (P<0.01); I²=57%
Test for overall effect: Z = 4.36
Test for subgroup differences: Chi²=25.66, df=6 (P<0.01)
0.2 0.5 1 2 5
Favors dV RAS
Favors LapVATS
B)
Blood Transfusions dV-RAS Open
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Hysterectomy Cervical/Ca 1032 2750 3.3% 0.10 [0.04, 0.26], p<0.01
Subgroup heterogeneity: I²=69%, p=0.18
Radical Prostatectomy 194691 284888 54.5% 0.18 [0.16, 0.21], p<0.01
Subgroup heterogeneity: I²=68%, p<0.01
Hysterectomy Endo/Ca 6531 20108 13.9% 0.26 [0.22, 0.30], p<0.01
Subgroup heterogeneity: I²=0%, p=0.64
Partial Nephrectomy 15468 32869 13.4% 0.51 [0.47, 0.55], p<0.01
Subgroup heterogeneity: I²=0%, p=0.45
Lung Lobectomy 5439 62939 10.5% 0.69 [0.51, 0.93], p<0.01
Subgroup heterogeneity: I²=71%, p=0.02
LAR/TME/SR 494 720 3.9% 0.48 [0.16, 1.47], p=0.20
Subgroup heterogeneity: I²=63%, p=0.07
Right Colectomy Not estimable
Total (95% CI) 223475 349733 100% 0.25 [0.21, 0.29], p<0.01
Heterogeneity: Tau²=0.26; Chi²=435.80, df=68 (P<0.01); I²=84%
Test for overall effect: Z = -15.54
Test for subgroup differences: Chi²=160.81, df=5 (P<0.01)
0.05 0.2 1 5 20
Favors dV RAS
Favors Open
C)
Hospital Stay dV-RAS LapVATS
Procedure Total Total Weight Mean Difference, IV, Random, 95% CI
Right Colectomy 1008 16109 3.9% -0.58 [-1.06, -0.11], p=0.02
Subgroup heterogeneity: I²=73%, p<0.01
Partial Nephrectomy 33028 9084 11.0% -0.57 [-0.97, -0.18], p<0.01
Subgroup heterogeneity: I²=97%, p<0.01
LAR/TME/SR 19011 38251 19.8% -0.50 [-0.85, -0.15], p<0.01
Subgroup heterogeneity: I²=94%, p<0.01
Radical Prostatectomy 76128 12128 16.6% -0.49 [-0.86, -0.12], p<0.01
Subgroup heterogeneity: I²=99%, p<0.01
Hysterectomy Endo/Ca 29570 13766 12.5% -0.53 [-0.90, -0.17], p<0.01
Subgroup heterogeneity: I²=98%, p<0.01
Lung Lobectomy 80644 252965 32.5% -0.47 [-0.65, -0.28], p<0.01
Subgroup heterogeneity: I²=99%, p=0
Hysterectomy Cervical/Ca 264 585 3.6% -0.60 [-1.31, 0.11], p=0.10
Subgroup heterogeneity: I²=77%, p<0.01
Total (95% CI) 252602 342778 100% -0.51 [-0.66, -0.36], p<0.01
Heterogeneity: Tau²=0.03; Chi²=481.25, df=48 (P<0); I²=90%
Test for overall effect: Z = -7.87
Test for subgroup differences: Chi²=0.49, df=6 (P=1.0)
-2 -1 0 1 2
Favors dV RAS
Favors LapVATS
D)
Hospital Stay dV-RAS Open
Procedure Total Total Weight Mean Difference, IV, Random, 95% CI
Hysterectomy Endo/Ca 30234 35697 14.4% -2.50 [-3.06, -1.93], p<0.01
Subgroup heterogeneity: I²=97%, p<0.01
Right Colectomy 8472 9407 25% -2.47 [-4.43, -0.51], p<0.01
Subgroup heterogeneity: I²=97%, p<0.01
Partial Nephrectomy 32845 63597 12.7% -2.01 [-2.56, -1.45], p<0.01
Subgroup heterogeneity: I²=96%, p<0.01
Hysterectomy Cervical/Ca 172 2052 25% -2.50 [-3.70, -1.30], p<0.01
Subgroup heterogeneity: I²=50%, p=0.13
LAR/TME/SR 8742 24662 13.4% -2.05 [-2.91, -1.19], p<0.01
Subgroup heterogeneity: I²=94%, p<0.01
Lung Lobectomy 64041 242272 13.5% -1.81 [-2.17, -1.45], p<0.01
Subgroup heterogeneity: I²=100%, p=0
Radical Prostatectomy 168748 98288 366% -1.41 [-1.81, -1.02], p<0.01
Subgroup heterogeneity: I²=100%, p=0
Total (95% CI) 313364 476336 100% -1.85 [-2.88, -1.82], p<0.01
Heterogeneity: Tau²=1.10; Chi²=34836.59, df=48 (P<0); I²=100%
Test for overall effect: Z = -15.41
Test for subgroup differences: Chi²=12.01, df=6 (P=0.06)
-10 -5 0 5 10
Favors Robotic
Favors Open
E)
30-day Postoperative Complications dV-RAS LapVATS
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Radical Prostatectomy 34758 8814 12.5% 0.72 [0.59, 0.88], p<0.01
Subgroup heterogeneity: I²=87%, p<0.01
Partial Nephrectomy 31583 8861 12.1% 0.81 [0.68, 0.97], p=0.02
Subgroup heterogeneity: I²=68%, p<0.01
Right Colectomy 9361 14975 5.9% 0.85 [0.59, 1.23], p=0.40
Subgroup heterogeneity: I²=72%, p<0.01
LAR/TME/SR 6114 9327 2.12% 0.89 [0.76, 1.03], p=0.13
Subgroup heterogeneity: I²=58%, p<0.01
Hysterectomy Endo/Ca 14007 11280 16.2% 0.96 [0.85, 1.10], p=0.54
Subgroup heterogeneity: I²=41%, p=0.06
Lung Lobectomy 24008 82756 26.3% 1.00 [0.91, 1.10], p=0.99
Subgroup heterogeneity: I²=77%, p<0.01
Hysterectomy Cervical/Ca 1125 717 3.4% 0.97 [0.60, 1.56], p=0.91
Subgroup heterogeneity: I²=44%, p=0.10
Total (95% CI) 121956 137140 100% 0.90 [0.84, 0.96], p=0.01
Heterogeneity: Tau²=0.04; Chi²=317.32, df=35 (P<0.01); I²=89%
Test for overall effect: Z = -3.10
Test for subgroup differences: Chi²=7.88, df=6 (P=0.25)
0.5 0.7 1 1.5 2
Favors dV RAS
Favors LapVATS
F)
30-day Postoperative Complications dV-RAS Open
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Hysterectomy Endo/Ca 8008 23008 16.4% 0.39 [0.33, 0.46], p<0.01
Subgroup heterogeneity: I²=47%, p=0.08
Radical Prostatectomy 206460 206754 39.9% 0.52 [0.45, 0.62], p<0.01
Subgroup heterogeneity: I²=97%, p<0.01
Partial Nephrectomy 32503 63804 13.4% 0.60 [0.52, 0.69], p<0.01
Subgroup heterogeneity: I²=63%, p<0.01
LAR/TME/SR 7617 9616 11.1% 0.68 [0.50, 0.93], p=0.01
Subgroup heterogeneity: I²=64%, p<0.01
Lung Lobectomy 5008 7617 13.7% 0.75 [0.66, 0.85], p<0.01
Subgroup heterogeneity: I²=30%, p=0.23
Hysterectomy Cervical/Ca 949 4641 55% 0.68 [0.47, 0.99], p=0.04
Subgroup heterogeneity: I²=50%, p=0.11
Right Colectomy Not estimable
Total (95% CI) 280975 315751 100% 0.58 [0.51, 0.67], p<0.01
Heterogeneity: Tau²=0.09; Chi²=264.56, df=42 (P<0.01); I²=84%
Test for overall effect: Z = -7.251
Test for subgroup differences: Chi²=47.73, df=5 (P<0.01)
0.05 0.2 1 5 20
Favors dV RAS
Favors Open

Figure 4:

Forest plots for 30-day readmissions for A) dV-RAS vs. lap/VATS and B) dV-RAS vs. open surgery, 30-day reoperations for C) dV-RAS vs. lap/VATS and D) dV-RAS vs. open surgery, and 30-day mortality for E) dV-RAS vs. lap/VATS and F) dV-RAS vs. open surgery. Black squares visually represent the effect size and the black line represents the 95% confidence interval. The black diamond represents the overall pooled effect size and its horizontal size represents the 95% confidence interval. Abbreviations: dV-RAS=da Vinci robotic-assisted surgery, lap/VATS=traditional laparoscopic or video assisted thoracoscopic surgery, IV=inverse variance, CI=confidence interval, LAR/TME/ISR=low anterior resection/total mesorectal excistion/intersphincteric resection, df=degrees of freedom. RD=risk difference

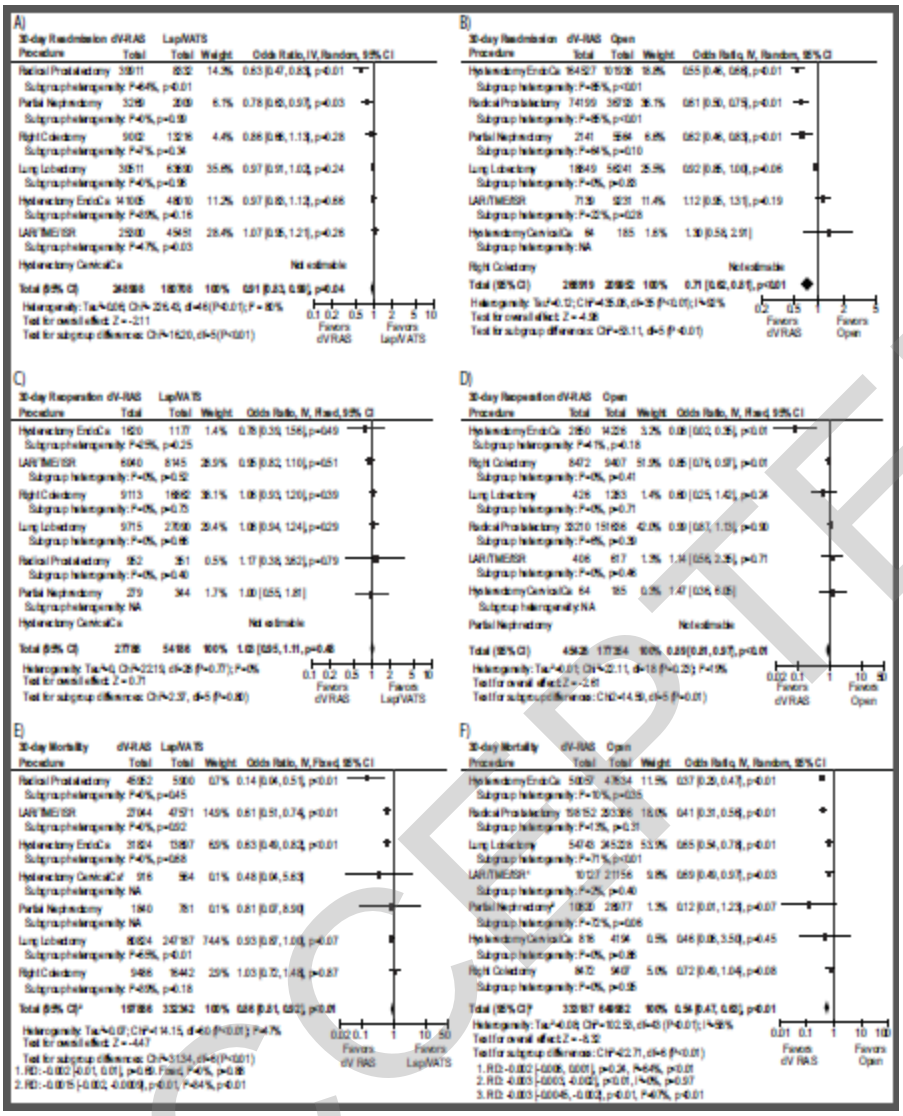
A)
30-day Readmission dV-RAS LapVATS
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Radical Prostatectomy 39011 8532 14.3% 0.63 [0.47, 0.83], p<0.01
Subgroup heterogeneity: P=64%, p<0.01
Partial Nephrectomy 3269 2000 6.1% 0.78 [0.60, 0.97], p<0.03
Subgroup heterogeneity: P=40%, p=0.09
Right Colectomy 5002 13216 4.4% 0.86 [0.65, 1.13], p=0.28
Subgroup heterogeneity: P=7%, p=0.36
Lung Lobectomy 30511 63900 35.6% 0.97 [0.91, 1.03], p=0.24
Subgroup heterogeneity: P=0%, p=0.99
Hysterectomy EndoCa 14105 48010 11.2% 0.97 [0.85, 1.12], p=0.68
Subgroup heterogeneity: P=69%, p=0.16
LAR/TME/SR 25000 49481 28.4% 1.07 [0.95, 1.21], p=0.26
Subgroup heterogeneity: P=47%, p=0.03
Hysterectomy CervicalCa Not estimable
Total (95% CI) 268868 180708 100% 0.91 [0.83, 0.99], p=0.04
Heterogeneity: Tau²=0.01; Chi²= 225.43, df=46 (P<0.01); I² = 80%
Test for overall effect: Z = -2.11
Test for subgroup differences: Chi²=16.20, df=5 (P=0.01)
0.1 0.2 0.5 1 2 5 10
Favors dVRAS
Favors LapVATS
B)
30-day Readmission dV-RAS Open
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Hysterectomy EndoCa 164527 101508 18.8% 0.55 [0.46, 0.66], p<0.01
Subgroup heterogeneity: P=65%, p<0.01
Radical Prostatectomy 74199 36723 38.1% 0.61 [0.50, 0.75], p<0.01
Subgroup heterogeneity: P=65%, p<0.01
Partial Nephrectomy 2141 1584 6.8% 0.62 [0.46, 0.83], p<0.01
Subgroup heterogeneity: P=64%, p=0.10
Lung Lobectomy 18849 56241 25.5% 0.92 [0.85, 1.00], p=0.06
Subgroup heterogeneity: P=0%, p=0.93
LAR/TME/SR 7139 5231 11.4% 1.12 [0.95, 1.31], p=0.19
Subgroup heterogeneity: P=22%, p=0.28
Hysterectomy CervicalCa 64 185 1.6% 1.30 [0.58, 2.91]
Subgroup heterogeneity: NA
Right Colectomy Not estimable
Total (95% CI) 268919 200952 100% 0.71 [0.62, 0.81], p<0.01
Heterogeneity: Tau²=0.12; Chi²=435.08, df=35 (P<0.01); I²=92%
Test for overall effect: Z = -4.96
Test for subgroup differences: Chi²=53.11, df=5 (P<0.01)
0.2 0.5 1 2 5
Favors dVRAS
Favors Open
C)
30-day Reoperation dV-RAS LapVATS
Procedure Total Total Weight Odds Ratio, IV, Fixed, 95% CI
Hysterectomy EndoCa 1620 1177 1.4% 0.76 [0.59, 1.56], p=0.49
Subgroup heterogeneity: P=25%, p=0.25
LAR/TME/SR 6040 8145 28.9% 0.95 [0.82, 1.10], p=0.51
Subgroup heterogeneity: P=0%, p=0.52
Right Colectomy 9113 16982 38.1% 1.08 [0.93, 1.26], p=0.39
Subgroup heterogeneity: P=0%, p=0.75
Lung Lobectomy 9715 27000 29.4% 1.08 [0.94, 1.24], p=0.29
Subgroup heterogeneity: P=0%, p=0.98
Radical Prostatectomy 952 351 0.5% 1.17 [0.39, 3.52], p=0.79
Subgroup heterogeneity: P=0%, p=0.40
Partial Nephrectomy 279 364 1.3% 1.00 [0.55, 1.81]
Subgroup heterogeneity: NA
Hysterectomy CervicalCa Not estimable
Total (95% CI) 27788 54186 100% 1.03 [0.95, 1.11], p=0.48
Heterogeneity: Tau²=0; Chi²=22.13, df=28 (P=0.77); I²=0%
Test for overall effect: Z = 0.71
Test for subgroup differences: Chi²=2.37, df=5 (P=0.80)
0.1 0.2 0.5 1 2 5 10
Favors dVRAS
Favors LapVATS
D)
30-day Reoperation dV-RAS Open
Procedure Total Total Weight Odds Ratio, IV, Fixed, 95% CI
Hysterectomy EndoCa 2850 14226 3.2% 0.08 [0.02, 0.35], p<0.01
Subgroup heterogeneity: P=41%, p=0.18
Right Colectomy 8472 9407 51.9% 0.85 [0.76, 0.97], p=0.01
Subgroup heterogeneity: P=0%, p=0.41
Lung Lobectomy 426 1283 1.4% 0.60 [0.25, 1.42], p=0.24
Subgroup heterogeneity: P=0%, p=0.71
Radical Prostatectomy 35210 151626 42.0% 0.99 [0.87, 1.13], p=0.90
Subgroup heterogeneity: P=6%, p=0.35
LAR/TME/SR 406 617 1.3% 1.34 [0.56, 2.35], p=0.71
Subgroup heterogeneity: P=0%, p=0.46
Hysterectomy CervicalCa 64 185 0.3% 1.47 [0.36, 6.05]
Subgroup heterogeneity: NA
Partial Nephrectomy Not estimable
Total (95% CI) 47428 177234 100% 0.89 [0.81, 0.97], p=0.01
Heterogeneity: Tau²=0.01; Chi²=22.11, df=18 (P=0.23); I²=19%
Test for overall effect: Z = -2.61
Test for subgroup differences: Chi²=14.59, df=5 (P=0.01)
0.02 0.1 1 10 50
Favors dVRAS
Favors Open
E)
30-day Mortality dV-RAS LapVATS
Procedure Total Total Weight Odds Ratio, IV, Fixed, 95% CI
Radical Prostatectomy 45952 5000 0.7% 0.14 [0.04, 0.51], p<0.01
Subgroup heterogeneity: P=0%, p=0.45
LAR/TME/SR 27044 47971 14.9% 0.81 [0.51, 0.74], p<0.01
Subgroup heterogeneity: P=0%, p=0.92
Hysterectomy EndoCa 31824 13887 6.9% 0.83 [0.49, 0.82], p<0.01
Subgroup heterogeneity: P=0%, p=0.68
Hysterectomy CervicalCa 916 964 0.1% 0.48 [0.06, 5.63]
Subgroup heterogeneity: NA
Partial Nephrectomy 1840 761 0.1% 0.81 [0.07, 8.50]
Subgroup heterogeneity: NA
Lung Lobectomy 80824 247187 74.4% 0.93 [0.87, 1.00], p=0.07
Subgroup heterogeneity: P=6%, p<0.01
Right Colectomy 9486 16442 2.9% 1.03 [0.72, 1.48], p=0.87
Subgroup heterogeneity: P=0%, p=0.18
Total (95% CI)* 197866 332362 100% 0.86 [0.81, 0.92], p<0.01
Heterogeneity: Tau²=0.01; Chi²=114.15, df=40 (P<0.01); I²=65%
Test for overall effect: Z = -4.47
Test for subgroup differences: Chi²=31.34, df=6 (P<0.01)
1. RD: -0.002 [-0.01, 0.01], p=0.69; Fixed, P=0%, p=0.98
2. RD: -0.015 [-0.002, -0.0003], p<0.01, P=84%, p<0.01
0.02 0.1 1 10 50
Favors dV RAS
Favors LapVATS
F)
30-day Mortality dV-RAS Open
Procedure Total Total Weight Odds Ratio, IV, Random, 95% CI
Hysterectomy EndoCa 58057 47834 11.9% 0.57 [0.28, 0.47], p<0.01
Subgroup heterogeneity: P=0%, p=0.35
Radical Prostatectomy 158152 203316 18.0% 0.41 [0.31, 0.56], p<0.01
Subgroup heterogeneity: P=13%, p=0.31
Lung Lobectomy 54743 365228 53.9% 0.65 [0.54, 0.78], p<0.01
Subgroup heterogeneity: P=71%, p<0.01
LAR/TME/SR* 10127 21156 9.8% 0.69 [0.49, 0.97], p=0.03
Subgroup heterogeneity: P=2%, p=0.40
Partial Nephrectomy* 10533 28977 1.3% 0.12 [0.01, 1.23], p=0.07
Subgroup heterogeneity: P=72%, p=0.06
Hysterectomy CervicalCa 816 4154 0.5% 0.46 [0.06, 3.50], p=0.45
Subgroup heterogeneity: P=0%, p=0.85
Right Colectomy 8472 9407 5.0% 0.72 [0.49, 1.04], p=0.08
Subgroup heterogeneity: P=0%, p=0.35
Total (95% CI)† 332157 640982 100% 0.54 [0.47, 0.63], p<0.01
Heterogeneity: Tau²=0.09; Chi²=102.50, df=43 (P<0.01); I²=58%
Test for overall effect: Z = -8.32
Test for subgroup differences: Chi²=42.71, df=6 (P<0.01)
1. RD: -0.002 [-0.006, 0.001], p=0.24, P=64%, p<0.01
2. RD: -0.003 [-0.003, -0.002], p<0.01, I²=0%, p=0.57
3. RD: -0.003 [-0.004, -0.002], p<0.01, P=67%, p<0.01
0.01 0.1 1 10 100
Favors dV RAS
Favors Open

Table 1: Meta-analysis of outcomes pooled across surgical procedures

Comparison	Outcome	# Studies	dV-RAS Sample Size	Comparator Sample Size	Weighted dV-RAS	Weighted Comparator	Weighted Effect size [95% CI]	Effect p-value	Heterogeneity	IV Model
dV-RAS vs laparoscopy/VATS	Conversions	90	371369	593754	5.7% [5.6, 5.8]	11.6% [11.5, 11.7]	OR : 0.44 [0.40, 0.49]	**<0.01**	I^2=94%, p<0.01	R
	Operative Time	57	32162	51450	211.4 ± 74.0 min [210.6, 212.2]	193.7 ± 63.2 min [193.1, 194.2]	MD: 17.73 [9.80, 25.67]	**<0.01**	I^2=97%, p<0.01	R

Blood Loss	38	8421	9373	134.6 ± 134.6 mL [131.7, 137.5]	146.8 ± 412.6 mL [144.0, 149.7]	MD: -12.26 [-29.44, 4.91]	0.16	I^2=94%, p<0.01	R
Blood Transfusions	49	113636	117991	5.1% [5.0, 5.3]	5.9% [5.7, 6.0]	OR: 0.79 [0.72, 0.88]	**<0.01**	I^2=57%, p<0.01	R
Length of Stay	93	252632	342778	4.6 ± 3.1 day [4.57, 4.59]	5.1 ± 3.4 day [5.08, 5.10]	MD: -0.51 [-0.64, -0.38]	**<0.01**	I^2=98%, p<0.01	R
30-day	74	121256	137140	25.4%	26.5% [26.3,	OR: 0.90	**<0.01**	I^2=76%,	R

Postoperative Complications				[25.2, 25.7]	26.8]	[0.84, 0.96]	p<0.01	
30-day Readmissions	45	248998	180708	6.5% [6.4, 6.6]	7.2% [7.0, 7.3]	OR: 0.91 [0.83, 0.99]	**0.04**	I^2=80%, p<0.01	R
30-day Reoperations	29	27786	54186	5.0% [4.8, 5.3]	4.9% [4.7, 5.1]	OR: 1.03 [0.95, 1.11]	0.48	I^2=0%, p=0.77	F
30-day Mortality	79	197886	332342	1.18% [1.13, 1.23]	1.39% [1.35, 1.43]	OR: 0.86 [0.81, 0.92]	**<0.01**	I^2=47%, p<0.01	F
						RD: -0.0015 [-	**<0.01**	I^2=34%, p<0.01	F

						0.0022, -0.0009]			
Operative Time	55	62550	69876	213.9 ± 84.0 min [213.2, 214.6]	173.0 ± 65.1 min [172.5, 173.5]	MD: 40.92 [28.83, 53.00]	**<0.01**	I^2=99%, p<0.01	R
Blood Loss	44	13457	11290	174.2 ± 235.6 mL [170.2, 178.2]	467.6 ± 419.6 mL [459.9, 475.4]	MD: -293.44 [-359.53, -227.35]	**<0.01**	I^2=98%, p<0.01	R
Blood Transfusions	59	223564	348257	3.6% [3.5, 3.7]	11.2% [11.1, 11.3]	OR: 0.25 [0.21,	**<0.01**	I^2=94%, p<0.01	R

dV-RAS vs Open

						0.30]		
Length of Stay	84	313504	476366	4.0 ± 3.2 day [3.9, 4.0]	5.8 ± 4.1 day [5.80, 5.83]	MD: -1.85 [-2.09, -1.62]	**<0.01**	I^2=100%, p<0.01	R
30-day Postoperative Complications	61	267358	324114	17.9% [17.8, 18.1]	25.2% [25.1, 25.4]	OR: 0.56 [0.52, 0.61]	**<0.01**	I^2=94%, p<0.01	R
30-day Readmissions	36	275302	218335	5.8% [5.7, 5.9]	7.9% [7.8, 8.1]	OR: 0.71 [0.63, 0.81]	**<0.01**	I^2=92%, p<0.01	R
30-day	20	45428	177354	3.6%	4.15% [4.1,	OR: 0.89 [0.81,	**<0.01**	I^2=19%,	F

Reoperations				[3.4, 3.8]	4.2]	0.97]	p=0.23	
30-day Mortality	56	333187	649982	0.93% [0.90, 0.97]	1.49% [1.46, 1.52]	OR: 0.54 [0.47, 0.63] RD: -0.0034 [-0.0045, -0.0022]	**<0.01** **<0.01**	I^2=58%, p<0.01 I2=97%, p<0.01	R R

dV-RAS=da Vinci robotic-assisted surgery, VATS=video-assisted thoracoscopic surgery, IV=inverse variance, OR=odds ratio, MD=mean difference, RD=risk difference, R=Random, F=fixed, min=minute, mL=milliliter. Weighted values are proportion or mean, standard deviation, and [95% confidence interval].

Table 2: Subgroup meta-analysis by study type: da Vinci-robotic-assisted Surgery vs. laparoscopy/video-assisted thoracoscopic surgery

Outcome	Study Type	Procedures	# Studies	dV-RAS Sample Size	L/VATS Sample Size	Weighted dV-RAS Rate [95% Confidence Interval] Mean ± Standard Deviation	Weighted Comparator Rate [95% Confidenced Interval] Mean ± Standard Deviation	Weighted Effect size [95% CI]	Effect p-value	Heterogeneity	IV Model
Convert	RCT	HC/HE/L/P/PN/RC/RR	18	2384	2237	4.9% [4.0, 5.7]	8.6% [7.4, 9.7]	OR: 0.54 [0.38,	**<0.01**	I^2=0%, p=0.74	F

								0.75]			
	Data	HC/HE/L/P/PN/RC/ RR	53	366867	588917	5.7% [5.7, 5.8]	11.9% [11.9, 12.0]	OR: 0.43 [0.38, 0.48]	**<0.01**	I^2=96%, p<0.01	R
	PRO	HC/HE/L/P/PN/RC/ RR	20	2118	2600	4.8% [3.9, 5.7]	10.9% [9.7, 12.1]	OR: 0.56 [0.39, 0.78]	**<0.01**	I^2=19%, p=0.24	F
OT (min)	RCT	HC/HE/L/P/PN/RC/ RR	22	2682	2568	199.2 ± 52.6 [197.2, 201.2]	172.4 ± 50.1 [170.4, 174.3]	MD: 26.82 [12.21, 41.42]	**<0.01**	I^2=94%, p<0.01	R

	Data	HE/L/P/PN/RC/RR	16	27376	47140	247.5 ± 133.0 [245.9, 249.0]	218.6 ± 98.1 [217.7, 219.4]	MD: 28.91 [15.56, 42.26]	**<0.01**	I^2=97%, p<0.01	R
	PRO	HC/HE/L/P/PN/RC/RR	20	2104	1742	193.8 ± 45.8 [191.8, 195.7]	194.0 ± 46.6 [191.8, 196.2]	MD: -0.27 [-9.85, 9.31]	0.96	I^2=92%, p<0.01	R
Blood Loss (mL)	RCT	HC/HE/L/P/PN/RC/RR	15	2061	2018	91.1 ± 75.8 [87.8, 94.3]	96.9 ± 83.1 [93.2, 100.5]	MD: -5.79 [-18.74, 7.15]	0.38	I^2=81%, p<0.01	R
	Data	HE/PN/RC/RR	6	4688	5861	112.8 ±	120.8 ±	MD: -	0.58	I^2=89%,	R

						141.3 [108.7, 116.8]	174.3 [116.3, 125.2]	7.98 [-36.40, 20.43]		p<0.01	
	PRO	HC/HE/L/P/PN/RR	17	1672	1494	170.7 ± 154.4 [163.3, 178.1]	192.2 ± 164.3 [183.8, 200.5]	MD: -21.51 [-55.38, 12.35]	0.21	I^2=96%, p<0.01	R
BTx	RCT	HE/L/P/PN/RC/RR	9	1218	1231	5.2% [4.0, 6.5]	7.4% [5.9, 8.8]	OR: 0.72 [0.39, 1.34]	0.3	I^2=23%, p=0.26	F
	Data	HC/HE/L/P/PN/RC/RR	31	111271	116013	5.0% [4.9, 5.1]	5.8% [5.7, 5.9]	OR: 0.78 [0.70,	**<0.01**	I^2=68%, p<0.01	R

								0.87]			
	PRO	HC/HE/L/P/PN	10	1147	747	5.7% [4.4, 7.0]	6.6% [4.8, 8.4]	OR: 1.05 [0.67, 1.65]	0.82	I^2=0%, p=0.75	F
Hospital Stay (days)	RCT	HC/HE/L/P/PN/RC/ RR	16	1799	1948	5.3 ± 2.6 [5.2, 5.4]	6.0 ± 3.4 [5.8, 6.1]	MD: -0.66 [-1.12, -0.20]	**<0.01**	I^2=75%, p<0.01	R
	Data	HC/HE/L/P/PN/RC/ RR	58	248834	339320	4.5 ± 3.5 [4.5, 4.5]	5.0 ± 3.8 [5.0, 5.0]	MD: -0.48 [-0.62, -0.34]	**<0.01**	I^2=99%, p=0	R

	PRO	HC/HE/L/P/PN/RR	19	1999	1510	4.6 ± 1.9 [4.5, 4.7]	5.1 ± 2.3 [5.0, 5.2]	MD: -0.51 [-0.85, -0.17]	**<0.01**	I^2=88%, p<0.01	R
30-day Postop Comps	RCT	HC/L/P/PN/RC/RR	15	2304	1896	20.2% [18.6, 21.9]	23.8% [21.9, 25.7]	OR: 0.85 [0.73, 0.99]	**0.03**	I^2=48%, p=0.02	F
	Data	HC/HE/L/P/PN/RC/RR	39	117054	133768	25.5% [25.3, 25.8]	26.3% [26.1, 26.5]	OR: 0.91 [0.85, 0.99]	**0.02**	I^2=85%, p<0.01	R
	PRO	HC/HE/L/P/PN/RR	19	1898	1476	27.7%	31.8%	OR:	**0.02**	I^2=0%,	F

						[25.6, 29.7]	[29.5, 34.2]	0.81 [0.67, 0.97]		p=0.74	
30-day Readmit	RCT	L/RR	6	1154	1106	3.7% [2.6, 4.7]	4.4% [3.2, 5.6]	OR: 1.03 [0.67, 1.58]	0.9	I^2=48%, p=0.09	F
	Data	HE/L/P/PN/RC/RR	35	247609	179318	6.6% [6.5, 6.7]	7.3% [7.2, 7.4]	OR: 0.90 [0.82, 0.99]	**0.03**	I^2=83%, p<0.01	R
	PRO	L/PN/RC	4	235	284	4.4% [1.8, 7.0]	5.1% [2.6, 7.7]	OR: 0.86 [0.37,	0.74	I^2=0%, p=0.86	F

								2.03]			
30-day Reop	RCT	HE/L/P/RR	8	1674	1264	4.4% [3.4, 5.4]	5.2% [4.0, 6.4]	OR: 0.82 [0.55, 1.22]	0.32	I^2=0%, p=0.61	F
	Data	HC/HE/L/PN/RC/RR	12	25069	52141	5.1% [4.8, 5.3]	4.9% [4.7, 5.1]	OR: 1.04 [0.96, 1.12]	0.36	I^2=0%, p=0.49	F
	PRO	HE/L/P/RC/RR	8	1043	781	4.8% [3.5, 6.1]	5.4% [3.8, 7.0]	OR: 1.02 [0.56, 1.86]	0.94	I^2=0%, p=0.76	F

30-day Mortality	RCT	HC/HE/L/P/RC/RR	16	2489	2099	1.3% [0.8, 1.7]	2.5% [1.8, 3.2]	OR: 0.62 [0.26, 1.47] RD: -0.002 [-0.007, 0.003]	0.28 0.41	I^2=0%, p=0.95 I^2=0%, p=1.00	F F
	Data	HC/HE/L/P/PN/RC/RR	51	194333	329220	1.1% [1.1, 1.19]	1.2% [1.2, 1.3]	OR: 0.84 [0.74, 0.96]	**<0.01**	I^2=55%, p<0.01	R
	PRO	L/PN/RC/RR	11	1064	1023	0.5% [0.1, 1.0]	2.0% [1.1, 2.9]	OR: 0.65	0.47 0.62	I^2=0%, p=0.63	F F

								[0.20, 2.11] RD: -0.002 [-0.011, 0.007]		I^2=0%, p=0.98	

IV=inverse variance, OR=odds ratio, MD=mean difference, RD=risk difference, R=Random, F=fixed, RCT=randomized controlled trial, Data=Database study, PRO=prospective comparison study, Convert=conversions to open, OT=operative time, BTx=transfusions, Postop=postoperative, Comps=complications, Reop=reoperations, hysterectomy for cervical (HC) or endometrial (HE) cancer, L=lobectomy, P=prostatectomy, PN=partial nephrectomy, RC=right colectomy, RR=rectal resection.

Table 3: Subgroup meta-analysis by study type: dV-RAS vs. Open

Outcome	Study Type	Procedures	# Studies	dV-RAS Sample Size	Open Sample Size	Weighted dV-RAS Rate [95% Confidence Interval] Mean ± Standard Deviation	Weighted Comparator Rate [95% Confidence Interval] Mean ± Standard Deviation	Weighted Effect size [95% CI]	Effect p-value	Heterogeneity	IV Model
OT (min)	RCT	HC/HE/L/P/RR	7	748	701	196.3 ± 45.7 [193.0,	160.5 ± 38.5 [157.7,	MD: 35.79 [2.82,	**0.03**	I^2=98%, p<0.01	R

						199.6]	163.4]	68.76]			
	Data	HC/HE/L/P/PN/RC/RR	15	54913	64487	220.4 ± 123.2 [219.4, 221.4]	181.6 ± 87.9 [180.9, 182.3]	MD: 38.80 [24.62, 52.97]	**<0.01**	I^2=99%, p=0	R
	PRO	HC/HE/L/P/PN/RR	33	6889	4688	214.4 ± 71.0 [212.7, 216.1]	171.5 ± 59.0 [169.8, 173.2]	MD: 42.86 [24.01, 61.71]	**<0.01**	I^2=98%, p=0	R
Blood Loss (mL)	RCT	HC/HE/L/P/RR	8	755	709	142.2 ± 99.0 [135.2, 149.3]	365.8 ± 230.4 [348.8, 382.7]	MD: -223.5 [-413.9, -33.2]	**0.02**	I^2=98%, p<0.01	R

	Data	HC/HE/P/PN/RR	7	5034	5579	137.9 ± 171.4 [133.2, 142.6]	425.0 ± 436.4 [413.5, 436.4]	MD: -287.1 [-427.7, -146.5]	**<0.01**	I^2=99%, p<0.01	R
	PRO	HC/HE/P/PN/RR	29	7668	5002	192.7 ± 291.3 [186.2, 199.2]	508.4 ± 469.0 [495.4, 521.4]	MD: -315.6 [-395.6, -235.7]	**<0.01**	I^2=97%, p<0.01	R
BTx	RCT	HE/P	5	669	417	0.4% [0.0, 0.9]	3.4% [1.7, 5.2]	OR: 0.32 [0.09, 1.08]	0.07	I^2=0%, p=0.67	F
	Data	HC/HE/L/P/PN/RC/RR	32	215529	342891	3.7% [3.6, 3.7]	10.5% [10.4, 10.6]	OR: 0.25 [0.21,	**<0.01**	I^2=96%, p<0.01	R

								0.31]			
	PRO	HC/HE/P/PN/RR	22	7366	4949	3.8% [3.4, 4.2]	17.7% [16.6, 18.7]	OR: 0.21 [0.18, 0.25]	**<0.01**	I^2=20%, p=0.2	F
Hospital Stay (days)	RCT	HC/HE/L/P/RR	8	773	726	3.5 ± 2.3 [3.4, 3.7]	5.7 ± 3.1 [5.5, 5.9]	MD: -2.14 [-3.58, -0.70]	**<0.01**	I^2=98%, p<0.01	R
	Data	HC/HE/L/P/PN/RC/RR	50	305941	471036	3.8 ± 3.5 [3.8, 3.9]	5.8 ± 4.6 [5.8, 5.8]	MD: -1.93 [-2.18, -1.69]	**<0.01**	I^2=100%, p=0	R

	PRO	HE/L/P/PN/RR	26	6790	4604	4.3 ± 2.9 [4.3, 4.4]	6.0 ± 3.3 [5.9, 6.1]	MD: -1.62 [-2.09, -1.15]	**<0.01**	I^2=96%, p<0.01	R
30-day Postop Comps	RCT	HE/L/P/RR	7	714	452	16.2% [13.5, 18.9]	22.4% [18.5, 26.2]	OR: 0.70 [0.50, 0.98]	**0.04**	I^2=43%, p=0.10	F
	Data	HC/HE/L/P/PN/RC/RR	36	264054	322060	18.3% [18.1, 18.4]	25.7% [25.5, 25.8]	OR: 0.56 [0.51, 0.62]	**<0.01**	I^2=96%, p<0.01	R
	PRO	HC/HE/L/P/PN/RR	18	2590	1602	15.6% [14.2, 17.0]	22.0% [20.0, 24.0]	OR: 0.58 [0.39, 0.87]	**<0.01**	I^2=74%, p<0.01	R

30-day Readmit	RCT	HE/P	3	581	323	5.3% [3.5, 7.2]	7.2% [4.4, 10.1]	OR: 0.86 [0.47, 1.59]	0.64	I^2=0%, p=0.37	F
	Data	HC/HE/L/P/PN/RC/RR	28	273719	217222	5.9% [5.8, 6.0]	8.0% [7.9, 8.1]	OR: 0.72 [0.63, 0.82]	**<0.01**	I^2=93%, p<0.01	R
	PRO	HE/P/RR	5	1002	790	3.7% [2.5, 4.8]	8.5% [6.6, 10.4]	OR: 0.35 [0.08, 1.49]	0.15	I^2=80%, p<0.01	R
30-day Reop	RCT	HE/L	2	106	103	1.9% [0.0, 4.5]	1.9% [0.0, 4.6]	OR: 0.97 [0.13, 7.04]	0.98	I^2=0%, p=0.98	F

	Data	HC/HE/L/P/RC/RR	8	41212	175480	3.7% [3.5, 3.9]	4.2% [4.1, 4.3]	OR: 0.90 [0.83, 0.99]	**0.03**	I^2=46%, p=0.06	F
	PRO	L/P/RR	10	4110	1771	1.5% [1.1, 1.8]	3.2% [2.4, 4.0]	OR: 0.58 [0.37, 0.92]	**0.02**	I^2=0%, p=0.83	F
30-day Mortality	RCT	HE/L/P/RR	5	664	403	1.7%* [0.7, 2.7]	0% [0.0, 0.0]	OR: 2.90 [0.12, 72.60] RD: 0.002 [-0.008, 0.012]	0.52 0.69	NA I^2=0%, p=0.96	F F

	Data	HC/HE/L/P/PN/RC/ RR	40	328283	647214	0.9% [0.9, 1.0]	1.5% [1.5, 1.5]	OR: 0.55 [0.47, 0.63]	**<0.01**	I^2=60%, p<0.01	R
	PRO	P/PN/RR	11	4240	2365	0% [0, 0]	0.8% [0.5, 1.2]	OR: 0.12 [0.01, 1.13] RD: -0.001 [-0.004, 0.002]	0.06 0.47	I^2=0%, p=0.93 I^2=0%, p=1.00	F F

dV-RAS=da Vinci robotic-assisted surgery, IV inverse variance, OR=odds ratio, MD=mean difference, RD=risk difference, R=Random, F=fixed, RCT=randomized controlled trial, Data=Database study, PRO=prospective comparison study, Convert=conversions to open, OT=operative time, BTx=transfusions, Postop=postoperative, Comps=complications, Readmit=readmissions, Reop=reoperations, HC=hysterectomy for cervical cancer, HE=hysterectomy for endometrial cancer, L=lung lobectomy, P=radical prostatectomy, PN=partial nephrectomy, RC=right colectomy, RR=rectal resection (low anterior resection/total mesorectal excision/intersphincteric resection), min=minute, mL=milliliter. *Weighted proportion is based on odds ratio test (RD is 0.2%); there was a single death in the robotic group.