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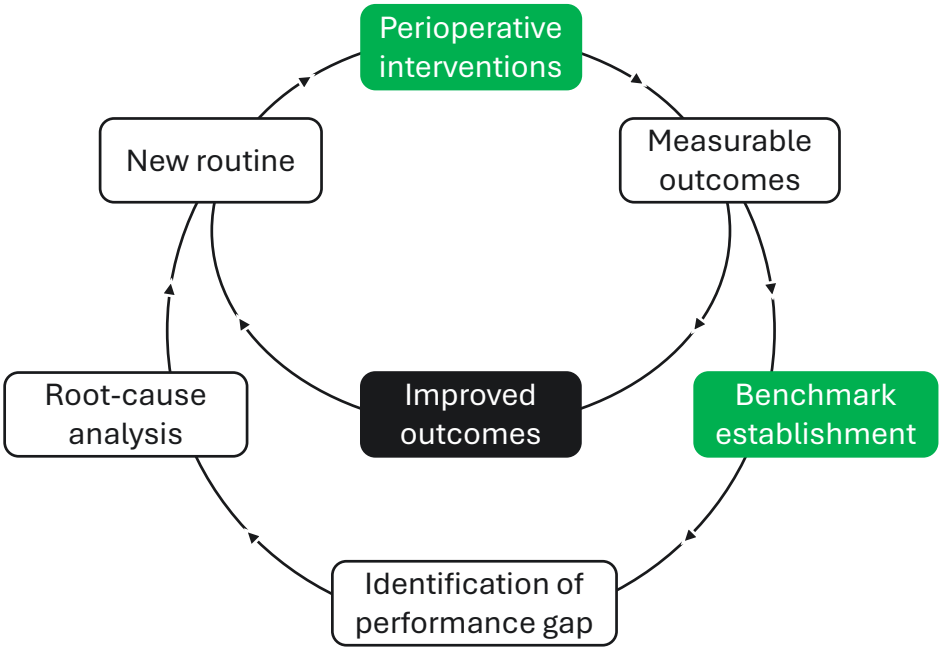
Improving Outcomes in Laparoscopic Upper Abdominal Surgery

Perioperative Intervention and Nationwide Benchmarking in Cholecystectomy and Bariatric Surgery



LINKÖPING UNIVERSITY

Ebba Kihlstedt Pasquier

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Improving Outcomes in Laparoscopic Upper Abdominal Surgery

Perioperative Intervention and Nationwide Benchmarking in Cholecystectomy and Bariatric Surgery

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Linköping 2026

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To Lily and Oscar

Every system is perfectly designed to get the result that it does.

— Paul Batalden, adapted from Arthur W. Jones

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LIST OF PAPERS

This thesis is based on the following original articles, referred to in the text by their Roman numerals.

I. **Pasquier EK**, Andersson E. *Pulmonary recruitment maneuver reduces pain after laparoscopic bariatric surgery: a randomized controlled clinical trial*. Surg Obes Relat Dis. 2018 Mar; 14(3): 386–392.
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II. **Kihlstedt Pasquier E**, Andersson E. *Pulmonary Recruitment Maneuver Reduces Shoulder Pain and Nausea After Laparoscopic Cholecystectomy: A Randomized Controlled Trial*. World J Surg. 2021 Dec; 45(12): 3575–3583.
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III. **Pasquier EK**, Andersson E, Ottosson J, Björnsson B, Sandström P. *Best achievable benchmarks in bariatric surgery: a nationwide registry study*. Surg Obes Relat Dis. 2026 Jun; 22(6): 628–635.
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IV. **Kihlstedt Pasquier E**, Andersson E, Österberg J, Sandström P, Björnsson B. *Elective Cholecystectomy Benchmarks: Nationwide Registry Study*. BJS Open. 2026 Oct; 10(5): zrag175.
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ABSTRACT

Background
Over the last 35 years, laparoscopic surgery has replaced open surgery as the standard approach for a wide array of procedures due to its many advantages. Although reduced morbidity and less postoperative pain are among these benefits, postoperative discomfort and complications remain important challenges, contributing to patient suffering and imposing an economic burden on patients, healthcare systems, and society.

Objectives
The overall aim of this thesis was to contribute to improving outcomes after laparoscopic upper abdominal surgery by evaluating a perioperative intervention and establishing nationwide benchmarks. The thesis focused on two of the most performed elective procedures: bariatric surgery (laparoscopic Roux-en-Y gastric bypass (LRYGB) and laparoscopic sleeve gastrectomy (LSG)) and elective laparoscopic cholecystectomy (ELC). *Papers I–II* aimed to reduce postoperative pain by evaluating a ventilator-piloted pulmonary recruitment maneuver (PRM), with postoperative nausea assessed as a secondary endpoint. *Papers III–IV* aimed to define quality-related, perioperative benchmarks, serving as standards of excellence, to support quality enhancement initiatives across the surgical community. The primary endpoint was severe postoperative complications, defined as Clavien-Dindo ≥III.

Methods
Papers I–II were prospective, randomized, controlled, and double-blind clinical trials designed to test the hypothesis that a PRM at the end of surgery could reduce postoperative pain intensity. *Papers III–IV* were retrospective, nationwide registry studies in which the Achievable Benchmarks of Care (ABC™) methodology was applied to establish target values for predefined variables. Logistic regression analyses were performed to identify preoperative risk factors for

severe complications, enabling risk-adjusted evaluation of these complications.

Results
Paper I: PRM improved the trajectory of postoperative pain the first 24 hours after bariatric surgery. Pain intensity was specifically lower in the intervention group 24 hours after surgery, and participants in the PRM group required less rescue opioid medication during the first 48 hours after surgery. There was no difference in nausea.

Paper II: In patients undergoing ELC, PRM reduced the incidence of postoperative shoulder pain. The intervention group also experienced lower incidence of nausea and a reduced need for antiemetics. No statistically significant differences were observed in overall pain intensity.

Papers III–IV: Several perioperative benchmarks were established for the different procedures. The benchmark for severe postoperative complications was 1.5% for LRYGB, 0.4% for LSG, and 1.0% for ELC. The risk factor diabetes mellitus increased the benchmark to 1.2% in the LSG cohort, and the risk factor ASA ≥III increased the benchmark to 1.5% in the ELC cohort.

Conclusions
PRM was associated with reduced overall postoperative pain following bariatric surgery and with a lower incidence of shoulder pain and nausea following laparoscopic cholecystectomy. In addition, nationwide benchmarking defined demanding yet achievable targets for perioperative outcomes in these procedures, including risk-adjusted benchmarks for postoperative complications. Together, these findings provide clinically relevant tools to support continued quality improvement in laparoscopic upper abdominal surgery.

Keywords: pulmonary recruitment, postoperative pain, postoperative nausea, benchmarking, surgical outcomes, quality improvement, bariatric surgery, cholecystectomy, laparoscopy

SAMMANFATTNING PÅ SVENSKA

Titthålskirurgi (laparoskopi) har under de senaste 35 åren successivt ersatt öppen kirurgi som standardmetod för många operationer, eftersom det ger mindre smärta, snabbare återhämtning och kortare vårdtid. Trots dessa fördelar medför postoperativ smärta, illamående och kirurgiska komplikationer fortfarande lidande för patienter och kostnader för både patient, sjukvård och samhälle.

Denna avhandling bygger på fyra studier som med två olika metoder syftar till att förbättra det perioperativa omhändertagandet vid två av Sveriges vanligaste planerade laparoskopiska ingrepp: gallblåseoperation (kolecystektomi) och fetmaoperation (bariatrisk kirurgi).

I de första två studierna (I och II) undersöktes om en standardiserad respiratorstyrd djupandning — på engelska pulmonary recruitment maneuver (PRM) — utförd vid slutet av titthålsoperationen, hade effekt på postoperativ smärta och illamående. Den bakomliggande teorin var att den koldioxidgas som skapar utrymme i bukhålan under operationen, orsakar efterföljande smärta genom uttänjning av bukväggen eller retning av en nerv som även innerverar hudområdet vid axlarna. En PRM sänker diafragmamuskeln och hjälper på så vis till att pressa ut kvarvarande koldioxid genom de ännu öppna såren i bukväggen.

Båda studierna inkluderade vuxna deltagare, som efter skriftligt medgivande slumpades till att få PRM eller rutinbehandling. Studierna genomfördes på Vrinnevisjukhuset i Norrköping. I *studie I* (patienter som genomgick bariatrisk kirurgi) minskade PRM den postoperativa smärtintensiteten 24 timmar efter operation och dessutom behovet av opioider. I *studie II* (patienter som genomgick planerad kolecystektomi) minskade PRM frekvensen av skuldersmärta och illamående, samt behovet av medicin mot illamående.

I de två sista studierna (III och IV) användes data från de nationella kvalitetsregistren Scandinavian Obesity Surgery Registry (SOReg) och Svenska Registret för Gallstenskirurgi och ERCP (GallRiks) för att med en metod kallad Achievable Benchmarks of Care (ABC™) fastställa riktmärken (benchmarks) för olika perioperativa kvalitetsparametrar, med särskilt fokus på frekvensen av allvarliga komplikationer efter kirurgi. Definitionen av allvarliga komplikationer var att de föranlett ett ingrepp i lokalbedövning eller narkos, medfört inläggning på intensivvårdsavdelning eller orsakat dödsfall. ABC™-metoden bygger på faktiska resultat, i detta fall från landets högst rankade kliniker, som tillsammans behandlat minst 10% av alla patienter, vilket innebar att riktmärkena blev högt ställda men ändå uppnåeliga.

I *studie III* inkluderades patienter som genomgått bariatrisk kirurgi med teknikerna gastrisk bypass eller sleeve gastrektomi under perioden 2012–2021. Riktmärket för allvarliga komplikationer var 1,5% för gastrisk bypass och 0,4% för sleeve gastrektomi. *Studie IV* omfattade patienter som genomgått planerad gallblåsekirurgi under perioden 2015–2023. Riktmärket för allvarliga komplikationer var 1%. Analyser gjordes för att identifiera eventuella riskfaktorer för allvarliga komplikationer i alla tre grupperna, varefter anpassade riktvärden beräknades för aktuella riskgrupper.

Sammantaget bidrar denna avhandling med två angreppssätt som kan främja bättre resultat efter titthålskirurgi i övre delen av buken: PRM, för minskad postoperativ smärta och möjligen även illamående, samt högt ställda riktmärken som underlag för jämförelser och inspiration till systematiskt förbättringsarbete bland kirurgiska enheter i Sverige och internationellt.

ABBREVIATIONS

ABC	Achievable benchmarks of care
ANOVA	Analysis of variance
ASA	American Society of Anesthesiologists
BDI	Bile duct injury
BMI	Body mass index
BPBC	Best patient in best center
CBD	Common bile duct
CCI	Comprehensive complication index
CD	Clavien-Dindo
CI	Confidence interval
cm H_2O	Centimeter water (pressure measurement)
CO_2	Carbon dioxide
CVS	Critical view of safety
ELC	Elective laparoscopic cholecystectomy
ERAS	Enhanced Recovery After Surgery
ERCP	Endoscopic retrograde cholangiopancreatography
$EtCO_2$	End-tidal CO_2 (the concentration of CO_2 in exhaled air)
GallRiks	Swedish registry for gallstone surgery and ERCP
IAP	Intraabdominal pressure
IOC	Intraoperative cholangiography

IQR	Interquartile range
IV	Intravenously
LOS	Length of hospital stay
LRYGB	Laparoscopic Roux-en-Y gastric bypass
LSG	Laparoscopic sleeve gastrectomy
mm Hg	Millimeter of mercury (pressure measurement)
NNT	Number needed to treat
NRS	Numeric rating scale
NSAID	Nonsteroidal anti-inflammatory drug
OR	Odds ratio
OS-MRS	Obesity surgery mortality risk score
PEEP	positive end-expiratory pressure
PONV	Postoperative nausea and vomiting
PRM	Pulmonary recruitment maneuver
PROM	Patient-reported outcome measure
PROSPECT	PROcedure SPECific postoperative pain managemenT
RCT	Randomized controlled trial
RRCT	Registry-based RCT
SD	Standard deviation
SOReg	Scandinavian Obesity Surgery Registry
VAS	Visual analogue scale
VRS	Verbal rating scale

THESIS AT A GLANCE

	Paper I	Paper II	Paper III	Paper IV
Approach	Quantitative, prospective	Quantitative, prospective	Quantitative, retrospective	Quantitative, retrospective
Design	Randomized controlled clinical trial	Randomized controlled clinical trial	Observational registry study	Observational registry study
Intervention /methodology	Pulmonary recruitment maneuver	Pulmonary recruitment maneuver	Benchmarking using the ABC™ methodology	Benchmarking using the ABC™ methodology
Patient inclusion period	2014–2016	2014–2018	2012–2021	2015–2023
Data sources	Peri- and post-operative questionnaires	Peri- and post-operative questionnaires	Prospective Quality Registry (SOReg)	Prospective Quality Registry (GallRiks)
Participants, number available for analysis	≥18 years old; bariatric surgery, LRYGB and LSG: 150 patients	≥18 years old; elective laparoscopic cholecystectomy: 147 patients	≥18 years old; bariatric surgery: 36 846 LRYGB and 15 246 LSG	≥18 years old; elective laparoscopic cholecystectomy: 48 564 patients
Statistical analysis	Descriptive; Chi-square; Mann–Whitney U; t-test; ANOVA	Descriptive; Chi-square; Mann–Whitney U; ANOVA	Descriptive; Bayesian volume adjustment; Logistic regression	Descriptive; Bayesian volume adjustment; Logistic regression
Main outcome measure	Pain intensity	Pain intensity	Severe postoperative complications	Severe postoperative complications
Aim	Reducing postoperative pain	Reducing postoperative pain	Defining benchmarks to inspire perioperative quality enhancements	Defining benchmarks to inspire perioperative quality enhancements

Abbreviations: ABC, achievable benchmarks of care. LRYGB, laparoscopic Roux-en-Y gastric bypass. LSG, laparoscopic sleeve gastrectomy. ANOVA, analysis of variance

PROLOGUE

My education is that of a medical doctor.

The art of surgery, my specialization.

My ethical duty is the continuous endeavor to improve in skills and outcomes,

and the responsibility to share my knowledge so that it may benefit future patients and contribute to the advancement of healthcare.*

This thesis is part of my endeavor to improve in skills and outcomes, and my humble attempt to share what insights it has brought.

Ebba Kihlstedt Pasquier
October 2026

*The Physician's Pledge, *World Medical Association, Declaration of Geneva, adopted September 1948; amended October 2017.*

BACKGROUND

Laparoscopic surgery

Evolution to revolution

Laparoscopy was first experimentally performed with a cystoscope on a dog by the German gastroenterologist and surgeon Georg Kelling in 1901,[1] then introduced clinically, as a diagnostic tool for humans, by the Swedish internist Hans Christian Jacobaeus, who coined the term laparoscopy in 1910 (Figure 1).[2]

Figure 1. The birth of human laparoscopy, Jacobaeus 1910.[3]

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Technological advances during the mid-20th century enabled the progress of interventional laparoscopy; in optics and fiber-optic illumination allowing visualization of body cavities while standing,

combined with development of electrocautery, and of gas insufflation devices allowing monitored cavity distention and space to operate.

It was first used in the field of gynecology, culminating in German gynecologist Kurt Semm's spectacular laparoscopic appendectomy in 1980. The progress was not well received, and its publication was not accepted until 1983.[4] This was considered the first advanced laparoscopic intervention, and it marked the beginning of the minimally invasive era.

In an interview Semm (Figure 2) described the reactions: "Both surgeons and gynecologists were angry with me, they were throwing stones at me. All my initial attempts to publish on laparoscopic appendectomy were refused, with the comment that such nonsense does not and will never belong to general surgery".[5]

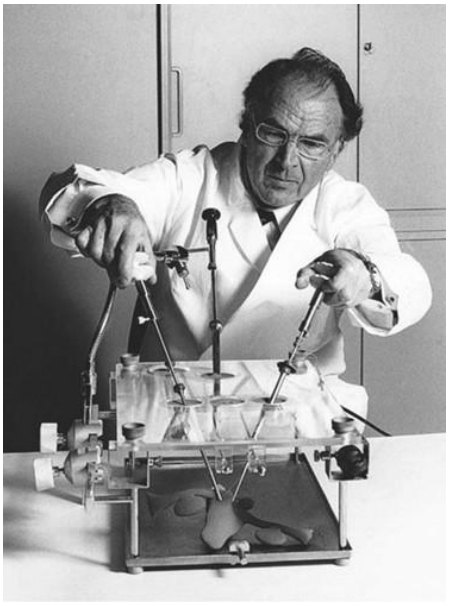

Figure 2. Kurt Semm with the "pelvi-trainer" he developed for laparoscopic surgery education.[6]

© J. Van Robays, Kurt Semm (1927–2003). CC BY-NC 4.0.

The first laparoscopic cholecystectomy was performed by the German surgeon Erich Mühe in 1985, using a self-designed direct-vision "galloscope".[7] The results were presented in German, and they too were seen with harsh skepticism by the surgical community. French surgeon Philippe Mouret performed the first video-assisted laparoscopic cholecystectomy in 1987, showed the video to his doubting compatriot François Dubois in 1988, who became the first to publish the results, shortly followed by Perissat in 1989.[8-11]

This ultimately sparked the revolutionary transition from open surgery to minimally invasive surgery, now the preferred approach for many surgical procedures and an integral component of contemporary surgical practice. Laparoscopic interventions are now safe, and, compared to open surgery, result in less postoperative pain, reduced hospital stays, faster healing and return to ordinary activities, and considerably smaller scars.[12]

Pneumoperitoneum

Laparoscopic surgery requires insufflation of gas to visualize the internal organs and to allow space for the surgeon to operate. This is commonly referred to as pneumoperitoneum. Air was used when laparoscopy was first introduced. It was soon realized, however, that air or oxygen was incompatible with electrocautery devices due to risk of explosions.[3] Further, the slow absorption led to prolonged postoperative pain, and there was a risk of gas embolism.[3] Carbon dioxide (CO_2) was introduced as early as in the 1920s and is still the preferred gas due to its favorable properties.[13] CO_2 is incombustible, and therefore safe with energy devices; it has high blood solubility, and therefore the risk of gas embolism is low, and it is easily eliminated via the lungs; lastly, it is both reasonably priced and widely available.[13] Technically, the pneumoperitoneum is a capno-peritoneum, but the original term from when air was used remains the standard concept.

There are two main methods to achieve pneumoperitoneum; the closed and open techniques. With the closed technique pneumoperitoneum is created without prior visualization of the abdominal cavity, mostly using a Veress needle. This device was named after Hungarian internist János Veres, who initially invented it in the 1930s to create pneumothorax, as a treatment for tuberculosis.[14] With the open, also called Hasson technique, after the American gynecologist Harrith Hasson who first described it in 1971, the abdominal cavity is accessed under direct vision through a small periumbilical incision prior to gas insufflation.[15]

Although laparoscopic surgery is preferred over open surgery due to less patient morbidity, the establishment of pneumoperitoneum carries particular physiological and undesirable effects.

Physiological effects

The physiological effect of pneumoperitoneum is generally associated with the increased intraabdominal pressure (IAP). Elderly patients, children and patients with cardiovascular comorbidities may be particularly sensitive, whereas in otherwise healthy patients, classified as I–II according to the American Society of Anesthesiologists (ASA), the physiological effects are minor.[16]

Hemodynamic alterations

The creation of pneumoperitoneum influences patient hemodynamics. The effect is greatest during the insufflation phase, when the IAP increases. The venous return to the heart is reduced, as are subsequently preload and cardiac output, leading to reduced blood pressure.[16] This triggers a physiologic cascade involving the sympathetic nervous system, leading to increased heart rate and increased vascular resistance, aiming to increase afterload and arterial pressure.[16]

Apart from the vascular effects on the heart, the reduced venous flow from the lower limbs may increase the risk of thrombosis.[16] Patient positioning also influences the vascular effects. The reversed Trendelenburg position with the head up, as used in laparoscopic upper abdominal surgery, contributes to reduced venous return and cardiac output.[16] Adequate intravascular volume and early postoperative ambulation are important to mitigate these effects.[17] Pharmacological thromboprophylaxis with low-molecular-weight heparin should be considered in individuals with risk factors for thromboembolism.[17]

Cardiac arrhythmia

Pneumoperitoneum may cause cardiac arrhythmias via vagal reflexes due to peritoneal stretching, resulting in bradycardia, nodal rhythm, atrioventricular dissociation, or asystole. Hypercarbia, elevated CO_2 levels in blood, causes irritability of the heart which may provoke arrhythmia. Most intraoperative arrhythmias resolve following reduction of IAP and increased minute ventilation using 100% inspired oxygen.[18]

Pulmonary concerns

Pneumoperitoneum leads to systemic absorption of CO_2 across the abdominal wall, resulting in hypercarbia and potential acidosis. This effect increases with longer duration of surgery and higher IAP.[18] Hyperventilation, through the ventilator, and PEEP, improving gas exchange, are essential means to compensate the hypercarbia.[16]

Intraabdominal organs

The increased IAP during pneumoperitoneum has been shown to reduce kidney urine output, partly by inducing direct pressure on the kidney vascular supply, partly through increased levels of renin, aldosterone and possibly also antidiuretic hormone, leading to kidney water reabsorption.[19]

There is also a reduced splanchnic circulation caused by the increased IAP, reducing circulation to the digestive organs.[16] The clinical relevance of this appears minor, even in patients with obesity and preexisting liver steatosis.[19]

Intracranial pressure

Pneumoperitoneum also elevates intracranial pressure, with the magnitude of the increase correlating with intraabdominal pressure.[20,21] A comparative study by Cooke *et al.* found that headache and nausea were more frequent after laparoscopic than open abdominal surgery.[22] End-tidal carbon dioxide ($EtCO_2$) levels were similar between the groups, arguing against hypercarbia-induced cerebral vasodilation as an explanation for the difference.[22] The

authors suggested that the symptoms may instead be related to increased intracranial pressure through mechanical impairment of cerebral venous drainage.[22] Increased intracranial pressure is ordinarily without serious consequence, though caution is advised in patients with elevated baseline intracranial pressure or head trauma.[20]

Concerns

Entrance

The most critical risks to consider when entering the abdominal cavity are injury to internal organs and blood vessels. The incidence of intestinal perforation or major vascular injury has historically been found to be between 0 and 1%.[23] Another very rare risk is the formation of a gas embolus, which may result in acute heart failure, stroke and death. Gas emboli are mostly encountered during the insufflation phase, especially with intravascular insertion of the Veress needle.[16,24] Routine intraoperative monitoring with electrocardiogram (ECG) and $EtCO_2$ can detect signs of clinically relevant gas embolus, so that the effect may be counteracted.[16]

Other undesired effects of pneumoperitoneum are extraperitoneal insufflation with subcutaneous emphysema, capnothorax or capnomediastinum, which generally resolve spontaneously.[18]

Fortunately, serious events are so rare that randomized controlled trials (RCTs) have not been able to reflect differences in incidence between the two different techniques to achieve pneumoperitoneum. To date, there is insufficient high-quality evidence to recommend one technique over the other, and the debate continues.[23,25] Both in Sweden and internationally general surgeons tend to utilize the open technique, while gynecologists routinely use the closed technique.[23] In the clinical studies in this thesis, the Veress needle was used in bariatric surgery, while the Hasson technique was standard in cholecystectomy.

Postoperative pain

Pain following laparoscopic surgery may be intense, and laparoscopy-induced shoulder-tip pain appears in 35–80% of patients.[26,27] The pathogenesis of post-laparoscopic pain is considered multifactorial. Apart from the surgical trauma, it may be induced by diaphragmatic distension, peritoneal acidosis secondary to CO_2 absorption, and local inflammatory responses induced by pneumoperitoneum.[28] A widely accepted explanation for postoperative shoulder pain is irritation and stretching of the diaphragmatic peritoneum, resulting in stimulation of the phrenic nerve and referred pain to the shoulder through shared cervical nerve roots (C3–C5).[28,29]

Riedel and Semm published an article evaluating frequency of residual pneumoperitoneum and shoulder or subphrenic pain after gynecologic surgery in 1980, postulating that the two were most likely correlated.[30] In the 1990s, Fredman *et al.* tested the effect of active gas aspiration on pain during the first 4 hours following laparoscopic cholecystectomy, and noticed a reduced need of opioids, supporting the hypothesis.[31] Jackson *et al.* then found a correlation between the volume of residual gas and the degree of pain,[32] a finding confirmed in following publications.[33-35]

These observations encouraged the development of interventions aimed at reducing residual pneumoperitoneum, including active gas aspiration,[36] intraperitoneal saline instillation (displacing residual CO_2),[37] pulmonary recruitment maneuvers,[38] and combinations thereof[26]. Among these interventions, the pulmonary recruitment maneuver (PRM) is particularly interesting as it is simple to perform, requires no additional equipment or instrumentation other than in the surgical area of interest, and it can easily be incorporated into routine surgical practice.

Postoperative nausea and vomiting

Postoperative nausea and vomiting (PONV) are common following laparoscopic surgery. The etiology is multifactorial and includes

patient-related factors, anesthetic management, pain experience, and postoperative opioid use.[39,40] Lower intraabdominal insufflation pressures have been associated with reduced rates of PONV.[41] As many interventions developed to reduce postoperative pain after laparoscopy may also influence nausea, they have frequently been evaluated with regard to both outcomes.[26,38,42]

Intraabdominal pressure recommendation

From the previous section, it is clear that pneumoperitoneum and the resulting increase in IAP influence both physiology and clinical outcomes. To understand the rationale for selecting insufflation pressure during laparoscopy, it is helpful to first consider physiological IAP. Cobb *et al.* measured IAP in young, healthy adults in different situations. Lowest IAP was detected in the supine position (mean 1.8 mm Hg, SD 2.2), whereas it could be considerably higher during activities such as jumping or coughing while standing (>100 mm Hg), with no difference between men and women.[43] Sanchez *et al.* found a mean IAP of 6.5 mm Hg (range 0.2–16.2 mm Hg) in randomly selected, hospitalized patients with a mean age of 68 years.[44] A study evaluating middle-aged patients with a body mass index (BMI) > 40 kg/m^2 observed a mean IAP of 10.0 mm Hg (SD 0.6 mm Hg).[45] All studies remarked that the pressure correlated with increasing BMI. In conclusion, IAP is individual and influenced by elasticity of the abdominal wall and the diaphragm.[46] Persons with obesity, pregnancy or ascites may have a chronically elevated IAP, to which they have adjusted.[46,47]

Standard pressure setting is often ≥12 mm Hg in adults, aligned with the definition of intraabdominal hypertension.[48] A recent meta-analysis provided evidence that utilizing an IAP <10 instead of ≥ 10 mm Hg reduced the incidence of mild postoperative complications (Clavien-Dindo (CD) I–II), pain intensity, incidence of PONV, and length of hospital stay, all while preserving safety (level of evidence 1a).[41] There is also evidence of less postoperative pain using a low insufflation rate (2.5 L/min) compared to a high rate (7.5 L/min).[49]

Taking patient anatomy and abdominal wall elasticity into consideration, the lowest possible IAP and flow rate should be used during laparoscopy not to cause harm, all while allowing the surgeon to operate safely.

Enhanced Recovery After Surgery, ERAS

Following the introduction of minimally invasive surgery, another major transformation took place, this time in perioperative care. Danish professor of surgery Henrik Kehlet is recognized as a pioneer in developing the concept of Enhanced Recovery After Surgery (ERAS) in the 1990s.[50] ERAS is a perioperative strategy that aims to improve recovery and reduce postoperative complications by attenuating the surgical stress response and reducing postoperative pain through multiple interventions and interprofessional collaboration.[51] The ERAS study group was formed by European surgeons in 2001 and the international ERAS® Society was founded in Stockholm in 2010, with the objective to "*develop perioperative care and to improve recovery through research, education, audit and implementation of evidence-based practice*".[50] Beginning with elective colorectal surgery, the strategy has since proven successful in reducing hospital length of stay without jeopardizing quality of care in many surgical domains.[50]

Surgical trauma induces neurohumoral and metabolic changes through activation of the autonomic nervous system and the release of inflammatory mediators, which may contribute to catabolism, insulin resistance, and immunosuppression. Pain may impair organ function and delay mobilization and recovery, while nausea and postoperative ileus may delay enteral nutrition and further contribute to catabolism.[51]

The ERAS concept incorporates interventions throughout the perioperative process, beginning with preoperative patient education and optimization of comorbidities. Intraoperatively, PONV prophylaxis, goal-directed fluid management, and multimodal analgesia are recommended. Agents such as paracetamol and NSAIDs, together with regional analgesic techniques and infiltration of local anesthetics at the surgical site, are advocated to minimize opioid use and associated side effects. Nasogastric and urinary catheters should preferably be removed before leaving the operating

room. Postoperatively, early ambulation and enteral nutrition are encouraged. Antibiotic prophylaxis and thromboprophylaxis should be administered when indicated.[51,52]

Bariatric surgery and cholecystectomy

In this thesis, laparoscopic surgery is explored through the perspectives of bariatric surgery and cholecystectomy. The procedures are briefly described below and subsequently exemplified in the following sections to provide context for the research questions addressed.

Bariatric surgery and cholecystectomy are among the most commonly performed laparoscopic procedures worldwide.[53,54] The International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO) reported almost 600 000 interventions worldwide during 2023, in their latest report, while Brunt *et al.* stated that up to 1 000 000 cholecystectomies were performed annually only in the U.S.[54,55] In Sweden, approximately 5 000 laparoscopic bariatric procedures[56] and 17 000 laparoscopic cholecystectomies are performed annually, of which around 8 000 cholecystectomies are elective procedures[57].

Cholecystectomy

Gallstone disease is among the most common gastrointestinal disorders in Western populations, with a prevalence of approximately 10–20% among adults.[58] Its prevalence increases with age and is higher in women.[58] Obesity, rapid weight loss, metabolic syndrome, and genetic predisposition are established risk factors for gallstone formation.[58,59] Approximately 50–70% of individuals with gallstones remain asymptomatic, whereas symptomatic disease may present as biliary colic or complications such as cholecystitis, choledocholithiasis, cholangitis, and pancreatitis.[59]

After its introduction in the late 1980s, laparoscopic cholecystectomy soon became the standard treatment for gallstone disease.[60] Indications include symptomatic cholelithiasis and its complications, as well as biliary polyps with malignant potential.[61] The standard technique internationally is four-port laparoscopic cholecystectomy, which is evaluated in this thesis. Alternative

approaches developed to improve cosmetic results and potentially reduce postoperative pain include three-port cholecystectomy, single incision laparoscopic surgery (SILS), and variants of natural orifice transluminal endoscopic surgery (NOTES).[62]

Elective laparoscopic cholecystectomy (ELC) is nowadays often performed as ambulatory surgery, with patients discharged on the day of surgery.[57] ELC is one of the first procedures to be mastered as a young surgeon[63] and therefore performed by both residents and experienced surgeons.

The term *critical view of safety* (CVS) was coined by Strasberg *et al.* in 1995 to promote accurate identification of the cystic duct and artery and reduce the risk of bile duct injury (Figure 3a and 3b).[64] Identification of the CVS is now internationally recommended for the prevention of bile duct injury.[54,65] In Sweden, intraoperative cholangiography (IOC) is also generally performed to further delineate biliary anatomy, detect common bile duct (CBD) stones and facilitate detection of iatrogenic bile duct injuries.[66,67]

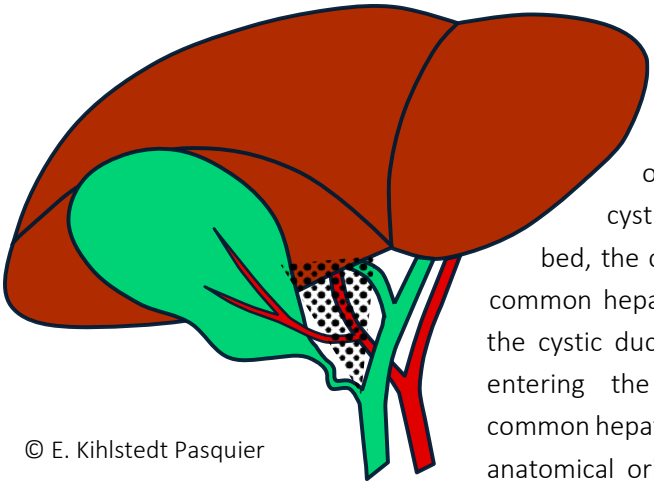

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Figure 3a. Critical view of safety, depicted by the dotted area and outlined by the cystic plate of the liver bed, the cystic duct, and the common hepatic duct, with only the cystic duct and cystic artery entering the gallbladder. The common hepatic duct is shown for anatomical orientation and does not need to be exposed.

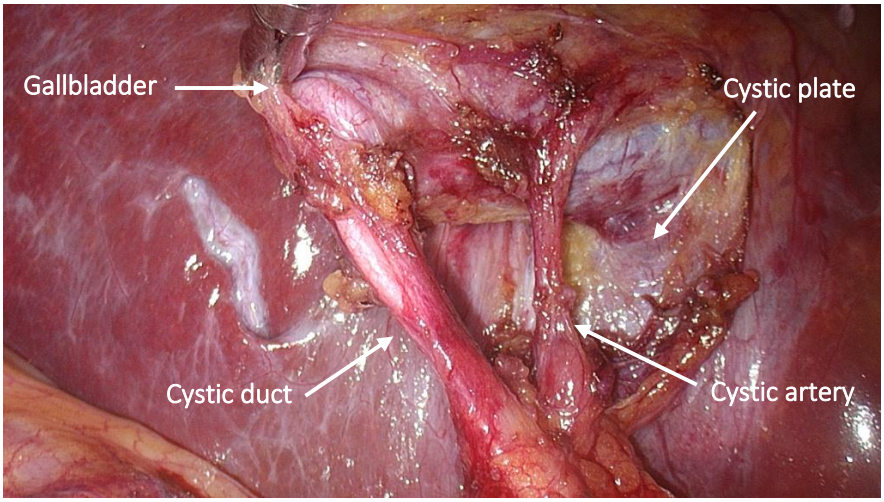

Figure 3b. Critical view of safety in a real patient.
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Despite the lack of specific ERAS guidelines for ELC, the same principles are generally applied to this population. Preoperative care for ELC in Sweden includes smoking cessation 4–6 weeks before surgery, while antibiotic prophylaxis is not recommended.[68] PONV prophylaxis and multimodal analgesia, including local anesthesia at the surgical incision sites, are routinely used. Thromboprophylaxis is prescribed postoperatively for patients considered at increased risk of thromboembolic events. Oral intake is allowed after awakening, early mobilization is encouraged, and patients are discharged on the day of surgery or the following day, depending on local practice and geographical factors.

A PROSPECT (PROcedure SPECific postoperative pain management) review from 2018 recommends a perioperative analgesic regimen including paracetamol, NSAID, dexamethasone, and infiltration of a local anesthetic at the port sites. The review additionally recommends low-pressure pneumoperitoneum (10–12 mm Hg), saline lavage, and aspiration of intraabdominal gas. Postoperatively, oral paracetamol and NSAIDs are advised, with opioids reserved for rescue analgesia due to their undesirable side effects.[69]

GallRiks

Cholecystectomies performed in Sweden are recorded in the Swedish Registry for Gallstone Surgery and Endoscopic Retrograde Cholangiopancreatography (GallRiks). The registry was officially launched on 1 May 2005 and is well established. At least 95% of all procedures are registered, and the internal validity is high (>97%).[70,71] GallRiks prospectively collects data regarding patient characteristics, operative details, and postoperative outcomes. Surgeons and endoscopists register surgical data, while local coordinators submit follow-up data concerning the first 30 days after surgery. Patients are informed about registration in GallRiks and of their opportunity to opt out of the registry.

The follow-up registration is potentially the most vulnerable component of the registry, as direct patient contact is not mandatory. Patients may receive postoperative care at hospitals other than the institution where the procedure was performed. If the operating unit lacks access to medical records from the treating hospital, complications managed elsewhere may go unreported, resulting in incomplete follow-up data. In *Paper IV*, several high-performing surgical facilities were specifically asked about this potential source of bias and confirmed access to medical records from regional hospitals, suggesting that the risk of underreporting was limited. Each year selected participating facilities undergo external validation by GallRiks auditors, with priority given to those demonstrating lower registry coverage.

Bariatric surgery

Obesity is a chronic disease with increasing global prevalence and is associated with an increased risk of type 2 diabetes, cardiovascular disease, several malignancies, reduced quality of life, and premature mortality.[72] Despite major advances in pharmacological treatment, bariatric surgery currently remains the treatment associated with the greatest and most durable weight loss and substantial improvement of obesity-related comorbidities.[72,73]

The definition of obesity is a BMI ≥30 kg/m², and surgery is indicated for individuals with a BMI ≥35 kg/m², in whom non-surgical weight-loss interventions have not accomplished durable results.[72] In addition to sustained weight reduction, bariatric surgery improves obesity-related comorbidities such as type 2 diabetes, hypertension, obstructive sleep apnea, and dyslipidemia.[74]

Several metabolic bariatric procedures have been developed over time. Today, laparoscopic Roux-en-Y gastric bypass (LRYGB) and laparoscopic sleeve gastrectomy (LSG) are the dominant bariatric procedures in Sweden and internationally (Figure 4).[56,74] Currently, approximately 85% of primary bariatric procedures in Sweden are LRYGB, reflecting a shift back towards LRYGB after a period of more equal use of LRYGB and LSG.[56] Globally, however, LSG constitutes the majority (57% in 2023) of primary bariatric procedures.[55]

In LRYGB a small gastric pouch is constructed and anastomosed to a Roux (alimentary) limb of the jejunum, typically 100–150 cm in length, through a gastrojejunostomy. The jejunum is divided approximately 60–100 cm distal to the ligament of Treitz, and the proximal segment (the biliopancreatic limb) is subsequently connected to the Roux limb through a jejunojejunostomy. This configuration allows ingested food to bypass the majority of the stomach, the duodenum, and a segment of the proximal jejunum.[75] The mesenteric defects created during LRYGB are routinely closed to reduce the risk of internal herniation.[76]

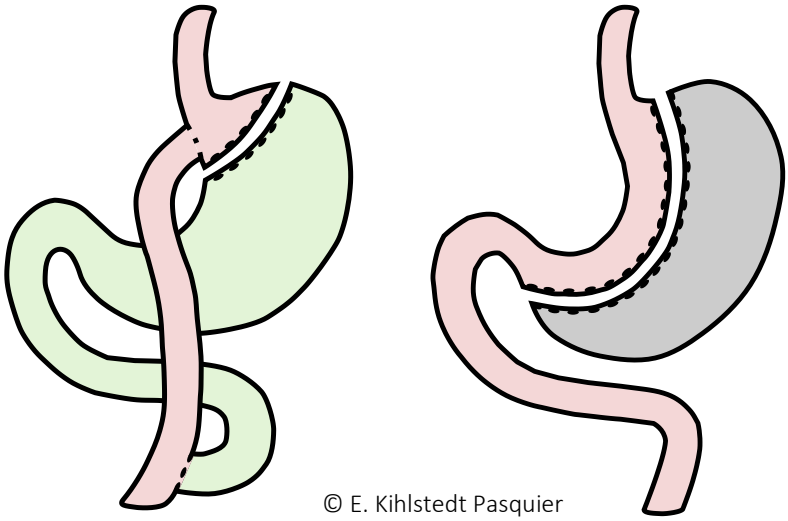

Figure 4. Schematic illustration of Roux-en-Y gastric bypass (left) and sleeve gastrectomy (right). Nutrients pass through the pink gastrointestinal tract. The light green color represents the disconnected stomach including the biliopancreatic tract and limb in LRYGB, while the grey area represents the resected stomach in LSG.

LSG is achieved by resecting roughly 70% of the greater curvature of the stomach, starting at about 5 cm proximally to the pylorus, to create a narrow tubular gastric remnant, while preserving the pylorus and gastrointestinal continuity.[77] Both techniques induce metabolic effects beyond restriction, including changes in gastrointestinal hormone signaling, such as postprandial secretion of glucagon-like peptide-1 and peptide YY, which may contribute to metabolic regulation and appetite control.[78]

The procedures have well-documented effects on weight loss and obesity-related comorbidities, and numerous studies have sought to establish which of them provides superior outcomes. At 5 years after surgery, the Swiss Multicenter Bypass or Sleeve Study (SM-BOSS) could not demonstrate a significant difference in percent excess BMI loss.[79] The larger Dutch Sleeve-Bypass trial similarly found no

significant difference in excess weight loss but demonstrated greater total weight loss in the LRYGB cohort.[80] A meta-analysis by Lee *et al.* reported a greater reduction in BMI from LRYGB the first three years postoperatively, but that remission of type 2 diabetes and hypertension were comparable.[81] Randomized evidence further indicates that LRYGB may provide greater improvement in dyslipidemia, and that gastroesophageal reflux disease is more frequent after LSG.[79,80,82] Major postoperative complications did not differ significantly between the procedures.[80,83]

The perioperative care for bariatric surgery includes preoperative assessment and education to prepare patients for long-term dietary modification, 4–8 weeks of smoking cessation to optimize wound healing and reduce cardiovascular complications, and a 2–4-week low-calorie diet to reduce liver volume and facilitate laparoscopic access.[84] PONV prophylaxis, antibiotic prophylaxis and thromboprophylaxis are also routinely administered. Additionally, the ERAS society guidelines recommend opioid-sparing anesthesia, to avoid opioid-related adverse effects.[84] Oral fluid intake can be initiated shortly after surgery, and Swedish patients are generally discharged from hospital on the first postoperative day, with a prescription for vitamin and mineral supplementation.[84]

SOReg

Bariatric procedures performed in Sweden are registered in the Scandinavian Obesity Surgery Registry (SOReg), a nationwide quality registry established in 2007. Since 2012, the national coverage has been >97%, and the internal validity is about 99%.[85] SOReg prospectively collects data regarding patient demography, surgery, and postoperative short- and long-term outcomes. There are follow-up checkpoints at 30 days after surgery, after 1 year, and 5, 10, and 15 years. Data is submitted by local registrars. Patients are informed of their participation in SOReg and of the possibility to opt out from the registry.

Completeness of short-term follow-up is supported by the standardized postoperative follow-up program used in Sweden, which includes patient contact approximately six weeks after surgery. This enables registration of postoperative events even when care has been sought outside the operating facility.

GallRiks' and SOReg's high national coverage and validity make them valuable resources for clinical research and quality assurance. Through the publication of annual quality reports, the registries facilitate the monitoring of trends in surgical techniques and outcomes over time.[86,87]

Need for improvement

Although laparoscopic surgery has transformed the treatment of gallstone disease and severe obesity, there is still room for improvement. Surgical morbidity persists, ranging from postoperative symptoms that delay recovery to life-threatening events requiring invasive treatment or intensive care. In the setting of high procedural volumes, even rare complications impose a substantial burden on patients, healthcare systems, and society. Consequently, for common procedures such as bariatric surgery and cholecystectomy, even modest improvements in outcomes may translate into substantial benefits at the population level.

In bariatric surgery, postoperative complications such as bleeding, gastrointestinal leakage, bowel obstruction, and nutritional deficiencies may lead to reinterventions, readmissions, and impaired quality of life. A recent meta-analysis by Kim *et al.* reported a notable incidence of both early and late complications, as well as substantial heterogeneity between studies.[88] Early complications within 30 days were 15% (95% CI 8–21%) for LRYGB and 9% (95% CI 4–15%) for LSG, while early reoperation indicating severe complications were lower, 2% (95% CI 1–4%) for LRYGB and 1% (95% CI 0–2%) for LSG.[88] Among the 20 prospective studies, including 1 984 patients, one patient (out of 843 RYGB procedures) died as a consequence of anastomotic leakage and subsequent multiorgan failure.[88]

Similarly, cholecystectomy is associated with clinically relevant risks, including bleeding, infection, and bile leakage, which may result in readmissions and reinterventions. The prospective observational AMBROSE study, encompassing 57 countries in 2022, reported a severe complication rate (Clavien-Dindo ≥IIIa) of 1.8% (320/17 443 patients) and a mortality rate of 0.1% (25/17 443 patients), based on the combined totals for elective and delayed cholecystectomies.[89] In *Paper IV*, these combined data are referred to as elective cholecystectomy.

Bile duct injury (BDI) remains one of the most severe complications of cholecystectomy as it may require complex reconstructive surgery, and is associated with increased morbidity, mortality, and impaired long-term quality of life.[54] A study by Törnqvist *et al.*, based on GallRiks data comprising 51 041 acute and elective cholecystectomies, reported a 1.5% incidence of any BDI, including leaks from the liver bed and cystic stump, and a 0.1% incidence of injuries requiring reconstructive surgery with a hepaticojejunostomy (major stricture, transectional injury, or injury above the hepatic confluence).[67] Likewise, a UK study by El-Dhuwaib *et al.* reported a 0.1% incidence of BDI requiring bile duct reconstruction (500/572 223 cholecystectomies)[90], while a meta-analysis by Burns *et al.*, reported incidences ranging up to 4.2% when less severe BDIs, including cystic stump leaks, were included.[91]

Apart from national incidence rates, the Swedish quality registries for bariatric surgery and cholecystectomy also reveal measurable between-facility variation in complication rates, readmissions, reoperations, conversion rates, and patient-reported outcomes (Table 1).[56,57] Part of the variation likely reflects random variation, differences in patient complexity, registration practices, or data completeness. However, the observed variation also raises the possibility that some differences in outcomes may be amenable to improvement.

In conclusion, there remains a need to define best attainable outcomes, and to identify strategies that may improve surgical results and reduce patient suffering.

Table 1. Performance variation between surgical facilities

	SOReg 2025		GallRiks 2025	
Outcome	Least	Most	Least	Most
Conversion to open surgery	3 conversions in the whole country, <0.1%		0	10.3% (68)
Intraoperative adverse event	0	13.5% (134)	0	5.4% (37)
Postoperative complication	0	14.3% (54)	0	45.8% (24)
SOReg CD ≥IIIb GallRiks CD ≥IIIa	0	8.3% (12)	0	12.5% (24)
Readmission within 30 days	0	12.8% (141)	0	21.4% (14)
Bile duct injury *	NA	NA	0	9.1% (11)

Elective surgeries, regardless of indication or surgical method.[56,57] The total numbers of procedures are expressed in parenthesis. The cholecystectomies were not subordinated to other surgeries, such as transplantations or cancer surgery. All units included in the table above performed >10 interventions annually.

*Not including bile leaks from the liver bed or cystic stump.

NA, not applicable. CD, Clavien-Dindo.

Assessment of surgical outcomes

Reliable and standardized measurement of surgical outcomes is essential, both for evaluating specific perioperative interventions and for identifying opportunities for improvement. Robust outcome assessment enables meaningful comparison between studies, institutions, and healthcare systems, and provides the foundation for both clinical research and quality improvement initiatives. Consequently, a range of complementary outcome measures have been developed, including standardized classification systems and patient-reported outcome measures (PROMs), each capturing different dimensions of surgical care.

Intraoperative adverse events

Intraoperative adverse events encompass unintended events occurring between skin incision and completion of surgery. Such events may be procedure-related, including bleeding, injury to adjacent organs, anastomotic leakage, or bile duct injury, but may also arise from anesthesia, medication, or equipment failure.

Several classification systems for intraoperative adverse events have been proposed. Satava developed a framework to classify intraoperative events in the context of surgical simulation and surgical error assessment.[92] The three-grade classification was adapted for clinical use by Kazaryan *et al.* (Table 2).[93] Later, the ClassIntra classification was developed through international consensus, and subsequently validated for clinical use.[94,95] This classification has six grades, to resemble the Clavien-Dindo classification system (Table 2). Both systems categorize surgical errors according to their consequences and required corrective actions, and both include anesthesiologic adverse events.

Despite increasing interest in standardized reporting, no universally accepted classification system currently exists. Intraoperative adverse events are considered underreported, yet of considerable importance

for postoperative outcomes. The ICARUS (Intraoperative Complications Assessment and Reporting with Universal Standards) collaboration recently proposed international reporting standards, highlighting the continued evolution of this field.[96]

In *Paper III*, the refined Satava classification was chosen because of its simplicity. To better capture severe intraoperative events, the highest severity category (where errors go unrecognized) was expanded to include ClassIntra grade IV events, where identified errors with major consequences are included.

Table 2. Classifications of intraoperative adverse events

Refined Satava[93]	ClassIntra[95]
	0 No deviation from the ideal intraoperative course.
	I Any deviation from the ideal intraoperative course, without the need for additional treatment or intervention. E.g., ligation of blood vessel or extrasystoles.
I An error without consequence or near miss, managed without change of operative approach. E.g., suturing of intestinal injury and blood loss over normal range.	II Any deviation requiring minor treatment or intervention. E.g., suturing of non-transmural intestinal lesion and asymptomatic arrhythmia requiring medication.
II An error with further consequences for the patient, immediately identified and corrected. E.g., conversion to open surgery and limited resection of an injured organ.	III Any deviation requiring moderate treatment or intervention. E.g., limited intestinal resection and arrhythmia with transient hemodynamic effect.
III An unrecognized error that leads to a significant consequence or complication. The correction of the error is delayed, or a reintervention is required. E.g., common bile duct injury, intestinal injury, and a surgical object left intraabdominally. Also includes intraoperative bleeding requiring massive transfusion.	IV Any deviation requiring major and urgent treatment or intervention. Patient with life-threatening symptoms or event leading to permanent disability. E.g., massive transfusion/splenectomy and arrhythmia requiring defibrillation or intensive care.
	V Any deviation leading to the intraoperative death of the patient.

Postoperative complications

Postoperative complications are among the most frequently reported surgical outcomes and constitute a major source of postoperative morbidity, mortality, and healthcare utilization. The Clavien–Dindo classification is an established grading system for postoperative complications and categorizes complications according to the treatment required to manage them (Table 3).[97] The classification ranges from minor deviations from the normal postoperative course to death, with only the most severe complication experienced by a patient being reported.[97] Katayama *et al.* proposed supplementary specifications to the CD classification, providing guidance for grading previously unspecified events, such as nasogastric decompression due to postoperative ileus.[98] These specifications proved useful in *Paper IV*, where CD grades were derived from registry data. The CD classification was introduced as a reporting variable in SOReg in 2010 and in GallRiks in 2021.[56,57]

The Comprehensive Complication Index (CCI) has emerged to provide a more comprehensive assessment of postoperative morbidity. This system incorporates all postoperative complications graded according to the CD classification into a continuous scale ranging from 0 to 100, aiming to capture the cumulative burden of complications experienced by a patient.[99]

Table 3. Clavien-Dindo classification of surgical complications

Grade	Definition
I	A deviation from ordinary postoperative course without the need for advanced pharmacological, endoscopic, radiologic or surgical interventions.
II	Complication requiring advanced pharmacological treatment such as antibiotics, anticoagulants or blood transfusion
III	Complication requiring endoscopic, radiologic or surgical intervention without (IIIa), or under (IIIb), general anesthesia
IV	Life-threatening complications, involving single (IVa) or multiple (IVb) organ failure, requiring intensive care unit management
V	Complication leading to the death of a patient

Patient-reported outcome measures, PROMs

Traditional surgical outcomes primarily reflect clinician-reported events, such as complications and mortality. While these metrics are essential, they do not fully capture the patient's perspective on postoperative recovery. Patient-reported outcomes are defined as reports of a patient's health status that come directly from the patient, without external interpretation, thereby providing information not captured by clinical assessment alone.[100] Consequently, PROMs, often in the form of questionnaires, have gained increasing importance as complementary endpoints in surgical research and quality assessment.[101,102]

The Standardized Endpoints in Perioperative Medicine (StEP) initiative has proposed six PROMs central to evaluating postoperative recovery: pain intensity (using a numeric rating scale); incidence of PONV; time to mobilization; time to gastrointestinal recovery (defined by time to tolerate oral diet); sleep disturbance; and a short quality of recovery score.[103] These outcomes are recommended for inclusion in clinical trials to enable meaningful comparison between treatments.

Studies incorporating PROMs may facilitate discrimination between treatment strategies based on perioperative patient experience, even in the absence of measurable differences in major complication rates.[102] Together, clinician-reported outcomes and PROMs provide complementary perspectives on surgical care. Their combined use enables a more holistic assessment of treatment effectiveness and supports efforts to improve patient-centered aspects of care.

Perspectives on pain and nausea

Following laparoscopic surgery, postoperative pain and PONV are among the most frequently reported postoperative symptoms, and the focus of *Papers I* and *II*. Although generally transient, these symptoms are associated with patient distress, delayed recovery and reduced patient satisfaction.[29,104]

The International Association for the Study of Pain defines pain as "an unpleasant sensory and emotional experience associated with, or resembling that associated with, actual or potential tissue damage".[105] The definition underscores that pain is not merely a nociceptive signal from a sensory neuron, but a subjective experience influenced by psychological and social factors.

Consequently, self-report is considered the reference standard for assessing pain in communicative adults. For acute pain, such as that caused by surgery, defining location and intensity is generally considered sufficient.[106] Common unidimensional scales to measure pain intensity in cognitively competent adults are the Numeric Rating Scale (NRS), the Visual Analogue Scale (VAS), and the Verbal Rating Scale (VRS).[107]

Using the NRS, patients rate pain intensity on an 11-point scale ranging from zero (no pain) to ten (worst imaginable pain). The NRS has been found to be easy both to use and to interpret.[107] It is routinely used in postoperative care units and surgical wards in the county of Östergötland, where *Papers I* and *II* were conducted.

The VAS consists of a straight line with two end-anchors signifying no pain and worst imaginable pain, respectively, on which patients select a point corresponding to their perceived pain. The line is generally 100 mm long, and the distance from the "no pain"-anchor, measured in millimeters, is used to quantify pain intensity.[108] Like the NRS, the VAS is a validated and commonly used pain assessment scale in

clinical practice. However, it may be perceived as difficult to use, both cognitively and practically.[107,108]

With the VRS, patients describe their pain by selecting from a predefined set of between four and 15 descriptors, ranging from no pain to more severe pain. There is some evidence that the VRS may be preferred among older patients.[108] The VAS and NRS have been found to be more sensitive for detecting differences in pain intensity, with the NRS being the most responsive scale.[106,107]

Another aspect of the subjectivity of pain is determining what change on these scales represents a clinically relevant improvement in pain, referred to as the minimal clinically important difference (MCID). Cepeda *et al.* investigated the NRS alongside a four-descriptor VRS (none, mild, moderate or severe pain) in postoperative patients with a baseline NRS score above 4/10.[109] They found that patients with severe pain at baseline (NRS score 8) required a greater change in NRS score to achieve the same degree of pain relief as those with moderate pain at baseline (NRS score 6). For patients with moderate pain, a decrease of 1.3 NRS points (95% CI 1.2–1.4) corresponded to minimal improvement, whereas a decrease of 2.4 points (95% CI 2.2–2.6) corresponded to much improvement. Patients with severe pain required a decrease in NRS score of 1.8 points to experience a minimal improvement (95% CI 1.7–1.9). Myles *et al.* found that a change of 10 mm on the 100-mm VAS represented a clinically important decrease or increase in pain intensity after surgery.[110] They reasoned that this finding should be generalizable to the NRS, given the high correlation between the two scales.

While it is important to assess postoperative pain intensity at rest, patients should receive sufficient analgesia to facilitate mobilization and coughing, activities that may intensify pain. Assessing pain intensity only at rest may fail to detect relevant differences in the effectiveness of pain-relieving interventions when patients are active.[106] Despite this, a recent systematic review of 944 trials of

postoperative pain conducted over a ten-year period found that 53% had not assessed movement-evoked pain.[111]

Contrary to pain, PONV is not an inevitable consequence of surgery. It is, however, a common side effect of anesthesia and postoperative medication with opioids. When investigating a treatment for pain, as in *Papers I* and *II*, it is therefore logical to take PONV into consideration, as an intervention that reduces e.g., opioid requirements may also influence the occurrence of PONV.

The simplified risk score derived by Apfel *et al.* in 1999 is still used to identify patients at risk of PONV and thereby guide the use of antiemetic prophylaxis. [40] The score is based on four potential risk factors: female sex, a history of PONV or motion sickness, non-smoking status, and anticipated postoperative opioid use. In the original model, the risk of PONV increases with the number of risk factors, from 10% in patients with none of the factors to 80% in those with all four.[40]

Additionally, the fifth consensus guidelines for the management of PONV highlight an increased risk of post-discharge nausea in patients under 50 years of age and specifically identify bariatric surgery and laparoscopic cholecystectomy as procedures associated with an increased risk of PONV.[112] These guidelines recommend a multimodal approach to PONV prevention, including opioid-sparing anesthesia, goal-directed fluid therapy, and avoidance of volatile anesthetics. For adults at any risk for PONV, two different antiemetics are recommended for prophylaxis, with three to four agents suggested for patients with three or more risk factors. The guidelines advocate integrating this multimodal approach to PONV prevention into ERAS pathways.[112]

Like pain, PONV is a personal experience and, as such, is typically assessed as a patient-reported outcome. The PONV Intensity Scale, based on four patient questions addressing nausea and vomiting, is a validated instrument developed to identify clinically important

PONV.[113] While not specifically validated as measures of PONV, the NRS and VAS are commonly used to evaluate nausea intensity at a specific point in time. The NRS was used in the development of the Apfel risk score, and the VAS was used for comparison in the development of the PONV Intensity Scale.[40,113]

Determinants of surgical outcomes

Surgical outcomes are influenced by a complex interplay of factors beyond the technical conduct of an operation. These determinants may be related to the patient, procedure, surgeon, and healthcare system. Consequently, observed differences in outcomes do not necessarily reflect differences in quality of care alone. Consideration of these factors is therefore essential when interpreting surgical research and comparing outcomes across studies, surgeons, and institutions.

Patient-related factors

Patient characteristics, often referred to as case mix, are important determinants of surgical outcomes. Advanced age, obesity, smoking, frailty, male sex, and pre-existing comorbidity have all been associated with increased risks of postoperative complications, prolonged recovery, and mortality.[91,114-118]

The relative contribution of individual patient factors is, however, not always straightforward. The influence of age illustrates this complexity. Older age has been associated with postoperative morbidity after bariatric surgery, though results are inconsistent.[116,119] In contrast, retrospective studies suggest that both urgent and elective cholecystectomy can be performed safely in elderly patients, including nonagenarians.[117,120] However, the possibility that careful selection of elderly patients or high surgical expertise may have influenced these outcomes cannot be excluded. Overall, studies indicate that frailty, defined as a decreased physiological reserve, may better predict postoperative morbidity and mortality than chronological age.[121,122] Given the complexity of individual risk factors, several scoring systems have been developed to facilitate preoperative risk assessment.

The ASA Physical Status Classification is a widely used six-grade scoring system describing overall preoperative health status (Table 4).

It was initially introduced in 1941 and subsequently revised in 1961 and 2014.[123] Although originally intended as a measure of physiological reserve rather than operative risk, higher ASA classes have consistently been associated with increased postoperative morbidity and mortality.[124] Despite some interobserver variability, the ASA classification is therefore a valuable tool to characterize case mix in surgical research. Patients with ASA class IV or higher are generally not considered for elective surgery.

Table 4. The current ASA classification

Class	Definition
I	Healthy non-smoker
II	Mild, well-controlled systemic disease. Includes pregnancy and smoking.
III	Severe systemic disease, including body mass index ≥40 kg/m^2
IV	Systemic disease imposing a constant threat to life
V	Will not survive the next 24 hours without surgery
VI	Brain-dead

Since patients with a BMI ≥40 kg/m^2 are classified as ASA class III, the ASA classification has limited ability to distinguish between patients with obesity who have differing comorbidity burdens. To complement general risk assessment, patients undergoing bariatric surgery in Sweden are therefore also categorized according to the Obesity Surgery Mortality Risk Score (OS-MRS), a mandatory variable in SOReg. The OS-MRS is a procedure-specific risk prediction model incorporating five preoperative variables (age, BMI, sex, hypertension, and risk factors for venous thromboembolism), each yielding one point, to stratify patients according to postoperative mortality risk after gastric bypass surgery (Table 5).[118,125]

Table 5. OS-MRS classification

Class	Comorbidity score	Mortality rate*
A: low risk	0–1 point	0.2%
B: intermediate risk	2–3 points	1.1%
C: high risk	4–5 points	2.4%

*Mortality rate according to a multicenter validation study of the OS-MRS classification by DeMaria *et al*. in 2007.[125]

While clinical risk scores are useful for classifying patient risk, multivariable regression models (used in *Papers III–IV)* provide a means of adjusting for differences in patient case mix when comparing surgical outcomes between providers.[126] By estimating the independent association between patient-related risk factors and the outcome, these models enable risk-adjusted comparisons.

Procedural factors

Outcomes also vary according to the type and complexity of the procedure performed. Emergency surgery is associated with an increased risk of adverse events and postoperative complications, including urgent cholecystectomy.[127,128] In gallbladder surgery, acute or chronic inflammation may obscure anatomical landmarks and obliterate the normal planes of dissection, thereby increasing the risk of misidentification and bile duct injury.[129,130] As mentioned previously, an IOC (Figure 5) can delineate the biliary anatomy, guide surgical decision-making and facilitate early identification of bile duct injuries.[67,129]

Anatomical variation, not known beforehand, may increase procedural complexity and the risk of intraoperative injury. For example, a duplicated cystic artery may result in three structures appearing to enter the gallbladder, potentially complicating identification of the CVS.[131]

Figure 5.
Normal intraoperative cholangiogram, illustrating free passage of contrast from the liver to the duodenum and normal biliary anatomy, including the left and right hepatic ducts. A laparoscopic grasper is positioned around the narrow cystic duct. There is no bile leakage nor visible gallstones in the bile ducts.

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Specific procedural steps that may influence outcomes could be evaluated if documented. As described above, closure of mesenteric defects during LRYGB has been found to reduce long-term complications.[76] SOReg records closure of both the Petersen's space and the mesojejunal defect, which could therefore be evaluated as quality parameters in *Paper III*.

The three procedures examined in this thesis illustrate a gradient of technical complexity. ELC is generally technically straightforward when the gallbladder is not inflamed while bariatric surgery is technically more complex, involving gastrointestinal stapling and, in the case of LRYGB, construction of gastrointestinal anastomoses. Additionally, a thick abdominal wall and greater amounts of intra-abdominal adipose tissue may render the laparoscopic procedure technically demanding. The learning curve for ELC has been estimated to be substantially shorter than that of LRYGB.[63,132,133] Consequently, bariatric surgery is typically performed by surgeons with dedicated training and experience in bariatric techniques.

Vrinnevi Hospital in Norrköping, where participants in *Paper I* were recruited, is a regional center of excellence for bariatric surgery.

Surgeon- and team-related factors

Surgeon experience is another important determinant of surgical outcomes. Several studies have demonstrated associations between higher surgeon volume and improved outcomes across a range of procedures, supporting the concept that experience contributes to technical proficiency and perioperative decision-making.[134-136] Wallis *et al.* reported a small but measurable outcome improvement, including reduced mortality, among patients treated by female surgeons.[137] Two Swedish registry studies based on GallRiks data reported a similar pattern after cholecystectomy, and hypothesized that differences in risk-taking behavior or conscientiousness may contribute to the observed findings.[138,139]

However, the relative contribution of individual surgeon factors is difficult to separate from patient selection and institutional context. In addition, organizational factors within the operating room, including teamwork and safety culture, may influence surgical performance and patient outcomes.[140] Team familiarity is found to be favorable, possibly facilitating efficient communication and decision-making.[140]

Institutional factors

Institutional characteristics may influence outcomes independently of patient and surgeon factors. Hospital volume has been found to be positively correlated to improved outcomes after several procedures.[141] This has been proven repeatedly for bariatric surgery, especially concerning LRYGB, but also in LSG[142-144], while the effect has not been similarly established in cholecystectomy.[145,146]

Although hospital volume is frequently associated with improved outcomes, volume may serve as a surrogate marker for organizational

factors such as multidisciplinary expertise, standardized perioperative pathways, availability of specialized resources, accumulated institutional experience, or organizational culture. Recognition of variation between facilities has contributed to the development of quality registries and benchmarking initiatives aimed at identifying best practices and promoting continuous improvement.

RATIONALE FOR THIS THESIS

Surgical care has undergone remarkable technical progress over the last few decades, yet intraoperative adverse events, postoperative complications, and postoperative symptoms such as pain and nausea remain important causes of patient suffering and costs to healthcare and society. Improving surgical performance requires both identification of beneficial perioperative interventions and an understanding of outcome variation in clinical practice.

Randomized clinical trials provide causal evidence under controlled conditions and can directly inform clinical practice. In contrast, nationwide benchmarking enables evaluation of performance across healthcare facilities, offering a broader perspective on current practices and highlighting opportunities for improvement.

In this thesis, these complementary methodological approaches were applied to laparoscopic cholecystectomy and bariatric surgery, two standardized, high-volume procedures, with the potential to provide information that may support improvements in perioperative outcomes at both patient and population levels.

A pulmonary recruitment maneuver at the end of surgery had previously been associated with reduced postoperative pain after laparoscopic surgery with the patient in the Trendelenburg position. However, evidence was needed regarding the maneuver's usefulness in patients positioned in reverse Trendelenburg, such as those undergoing cholecystectomy or bariatric surgery.

Benchmarks had previously been defined for bariatric surgery, although the average performance of Swedish bariatric facilities exceeded those benchmark levels. Applying an alternative methodology could potentially result in benchmarks providing greater room for improvement. To the best of our knowledge, no benchmarks had previously been developed for laparoscopic cholecystectomy.

AIMS AND HYPOTHESES

The overall aim of this thesis was to contribute to the improvement of perioperative outcomes after laparoscopic upper abdominal surgery, focusing on two standardized and frequently performed laparoscopic procedures: cholecystectomy and bariatric surgery.

Specific aims and hypotheses

Paper I	Aim: To investigate whether a PRM reduces pain after laparoscopic bariatric surgery.
	Hypothesis: A PRM reduces postoperative pain after laparoscopic bariatric surgery
	Primary endpoint: Overall pain intensity
	Secondary endpoint: Nausea intensity
Paper II	Aim: To investigate whether a PRM reduces pain after elective laparoscopic cholecystectomy.
	Hypothesis: A PRM reduces postoperative pain after elective laparoscopic cholecystectomy
	Primary endpoint: Overall pain intensity
	Secondary endpoint: Nausea intensity
Paper III	Aim: To identify benchmarks for quality-related variables in laparoscopic bariatric surgery using nationwide data from SOReg.
	Primary endpoint: Severe complications, CD ≥III
Paper IV	Aim: To identify benchmarks for quality-related variables in elective laparoscopic cholecystectomy using nationwide data from GallRiks.
	Primary endpoint: Severe complications, CD ≥III

METHODS

In this thesis, two complementary methodological approaches were applied to two different types of laparoscopic upper abdominal procedures: cholecystectomy and bariatric surgery, the latter comprising LRYGB and LSG.

Papers I and II were prospective, double-blind, single-center RCTs, designed to evaluate the effect of PRM on postoperative pain. Randomization minimizes confounding and therefore provides a strong basis for causal inference when assessing the effects of an intervention. Participants, postoperative staff and the investigator analyzing data were blinded to treatment allocation. The trials were registered on ClinicalTrials.gov (NCT03026530 and NCT03026543) and approved by the Regional Ethical Review Board in Linköping, Sweden (Dnr 2014/120-31; amendment Dnr 2018/2-32).

In *Papers III and IV* a benchmarking methodology was utilized to define standards of excellence for LRYGB, LSG, and laparoscopic cholecystectomy. Both studies were retrospective registry studies, allowing analyses of real-world data from nationwide patient cohorts, covering several years and all surgical facilities in Sweden. The benchmarks focused on quality related perioperative outcomes, assessed intraoperatively and up to 30 days after surgery, with particular emphasis on severe postoperative complications. The studies were preregistered on ClinicalTrials.gov (NCT05785351 and NCT06692517) and approved by the Swedish Ethical Review Authority (Dnr 2022-04311-01; amendment Dnr 2024-06020-02).

Papers I and II

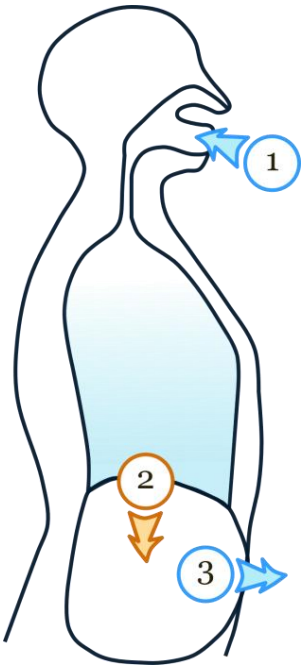
As previously mentioned, the pneumoperitoneum required for laparoscopic surgery is considered one of the contributors to postoperative pain. Prior studies of PRM had shown a reduction in shoulder pain intensity after gynecological surgery, where patients were kept in the Trendelenburg position during surgery.[38,147,148] One study including both inguinal hernia operations and cholecystectomy had shown a reduction in overall pain intensity.[149] All patients were healthy, categorized as ASA I–II.

We sought to determine whether a PRM could have an effect in patients undergoing solely upper abdominal surgery, where patient positioning and hence the effects of pneumoperitoneum differ from pelvic surgery. Furthermore, assuming that PRM would reduce pain, we aimed to evaluate the effectiveness of PRM in a real-world clinical setting, with ordinary surgeons, anesthesia staff and other healthcare personnel. Demonstration of a clinically meaningful benefit would support consideration of PRM as part of routine perioperative management.

Intervention: Pulmonary recruitment maneuver

A PRM consists of a temporary increase in airway pressure, causing inflation of the lungs. The maneuver was originally introduced to recruit atelectatic lung tissue and thereby improve oxygenation. A Swedish study by Rothen *et al.* in 1993, demonstrated that a sustained inflation to 40 cm H_2O resulted in radiological resolution of anesthesia-induced atelectasis.[150]

The maneuver results in caudal displacement of the diaphragm, which compresses the abdominal contents and transiently increases intra-abdominal pressure (Figure 6). If a PRM is performed at the end of laparoscopic surgery, after release of the pneumoperitoneum, this may facilitate evacuation of residual CO_2 through an open trocar, not yet removed. The maneuver is simple, rapid, and requires no additional equipment.



Ventilator-piloted PRM

In prior studies, the PRM had been performed manually. In collaboration with local and experienced anesthesiologists Helena Krook and Lars Abildgaard, a protocol for a standardized ventilator-piloted PRM was developed for *Papers I–II* (Table 6). This ensured that all patients received the same airway pressure, but with individually adapted breath volumes. The maneuver would last for 1 minute, corresponding to about six breaths with a total pressure of 40 cm H_2O. The duration was chosen to match the number of breaths used to perform PRM in previous studies.

Figure 6. Schematic illustration of PRM. 1) Pressure-controlled ventilation of the lungs. 2) The diaphragm descends, thereby increasing intraabdominal pressure. 3) CO_2 is expelled through an open port.

Randomized controlled trials

Laparoscopic bariatric surgery and laparoscopic cholecystectomy are common, standardized procedures, with short and generally uncomplicated hospital stays. To evaluate the usefulness of PRM in reducing postoperative pain in upper abdominal surgery, these surgical procedures therefore seemed ideal.

Participants and randomization

Adults aged ≥18 years, classified as ASA I–II, not including BMI as a variable, were considered for study inclusion. *Paper I* concerned patients scheduled for primary laparoscopic bariatric surgery, either LRYGB or LSG, with a BMI ≥35 kg/m². *Paper II* regarded patients

scheduled for ELC. Routine preoperative requirements included at least six weeks of smoking cessation. Patients undergoing bariatric surgery also followed a low-calorie diet (800 kcal/day) for four weeks before surgery, with the aim of achieving at least 5% total weight loss. This regimen was intended to reduce hepatic steatosis and thereby facilitate the surgical procedure.

Table 6. Protocol for pulmonary recruitment maneuver (PRM)

Requirement: The patient must be hemodynamically stable
Contraindication: Major blood loss

1. Change the ventilator settings as follows
    a. Fresh gas:
        i. Adjust O_2 % to the same value as FiO_2 % (to diminish risk of atelectasis)
        ii. Adjust Sev % to the same value as FiSev % (so that Sev % does not increase with increased air flow)
        iii. Set total air flow to 6 L/min (so as not to empty the air bellows of the ventilator)
    b. Ventilator mode: change to pressure-controlled ventilation (PCV)
    c. Values:
        i. Set inspiratory pressure to 20 cm H_2O
        ii. Set respiratory frequency to 6 breaths/min (to avoid hyperventilation)
        iii. Set positive end-expiratory pressure (PEEP) to 20 cm H_2O
2. Measure blood pressure (cancel the PRM if mean arterial pressure falls by >20%)
3. Run PRM for 1 minute
4. Return to pressure-controlled ventilation volume-guaranteed (PCV-VG) ventilation mode and reset values, or adjust them to the desired level

O_2, oxygen. FiO_2, fraction of inspired oxygen. Sev, sevoflurane

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As in previous trials with PRM, it was decided to reduce events likely to influence the experience of postoperative pain, excluding patients having multiple simultaneous surgeries, those converted to open surgery and patients with postoperative complications, classified as CD grade ≥ II. In *Paper II*, participants with acute cholecystitis, pancreatitis or cholangitis, and those requiring treatment with

endoscopic retrograde cholangiopancreatography (ERCP) were also excluded.

Participants were consecutively enrolled during preoperative consultation and randomized in a 1:1 ratio to either PRM or control using computer-generated block randomization. Sealed, sequentially numbered envelopes containing the allocation procedure were sent to theatre at the time of surgery.

Surgery and intervention

Bariatric surgery was performed by one of six experienced bariatric surgeons, with a fellow bariatric surgeon serving as assistant, while cholecystectomy was performed by any attending or resident surgeon at the surgical department. In the bariatric cohort, CO_2 was insufflated through a Veress needle inserted at Palmer's point in the left upper quadrant, while the open Hasson technique was used in the cholecystectomy group. All patients underwent surgery in the reversed Trendelenburg position. Gas pressure was maximum 16 mm Hg in the bariatric population, and 12 mm Hg in the cholecystectomy population. During exsufflation all participants were kept in the supine position, to avoid intraabdominal CO_2 retention.

The study envelopes were opened by the anesthesia staff, who, according to group allocation, either performed a PRM or maintained standard ventilation during the 1-minute gas exsufflation at the end of the procedure. The surgeons meanwhile applied gentle abdominal pressure in all participants (Figure 7).

In the bariatric cohort, there were two open ports in the upper abdomen during the exsufflation, and in the cholecystectomy cohort, gas escaped through one open port in the epigastrium. In the bariatric cohort, the fascia was not sutured, and the skin incisions were approximated with staples. In the cholecystectomy cohort, the gall bladder was evacuated through the umbilical incision, where the

fascia was sutured, before closing the skin incisions with intracutaneous sutures.

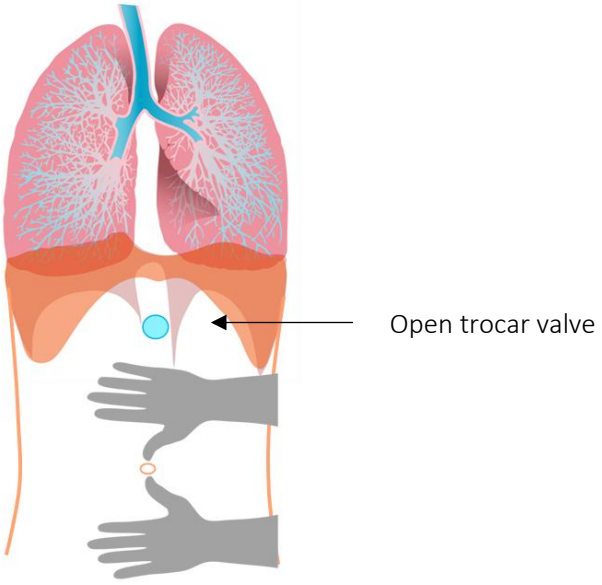


Figure 7. Schematic illustration of manual abdominal pressure during PRM.

Anesthetics and antiemetics

General anesthesia was induced with either remifentanil and propofol or alfentanil and thiopental. The latter regimen was used for patients with gastroesophageal reflux. Remifentanil plus either propofol or sevoflurane in oxygen-enriched air were used for anesthesia maintenance. The ventilator was set to pressure regulated volume control.

Preoperatively participants received oral paracetamol. Intraoperatively, local anesthesia was infiltrated subcutaneously at the port sites, 40 mL bupivacaine hydrochloride 5 mg/mL with epinephrine 5 µg/mL before trocar insertion in the bariatric group, and 20 mL of the same product in the cholecystectomy group. At the

end of surgery, participants received 30 mg ketorolac and/or morphine intravenously (IV). The morphine dose was registered for follow-up. All participants received antiemetic prophylaxis with 4 mg betamethasone and 0.5 mg droperidol IV. Those with previous PONV additionally received 4 mg ondansetron IV.

Postoperatively, participants were offered 1 g paracetamol every six hours. Rescue analgesia was offered as IV morphine in the post-anesthesia care unit (PACU), while 5 mg immediate-release oxycodone capsules were given in the surgical ward. Participants suffering from nausea received ondansetron IV. Doses were registered for follow-up.

Measurement of pain and nausea

After surgery, participants received a questionnaire with the same questions to answer on five different occasions during the first 48 hours (see Appendix). Answers were given by ticking boxes. A numeric rating scale (NRS) ranging from 0 (no pain or nausea) to 10 (worst imaginable pain or nausea) was used for evaluation of pain and nausea, respectively, at rest.

The numeric rating scale

The NRS was chosen due to its demonstrated validity, reliability, responsiveness, and feasibility to evaluate pain in clinical and postoperative settings.[151] Comparative validation studies have shown that the NRS performs similarly to the visual analogue scale while being easier for patients to understand and complete, resulting in lower rates of missing data and measurement error.[107] The scale is recommended for repeated assessment of patient-reported outcomes in perioperative clinical trials.[103] The NRS was complemented by questions related to mobilization.

As nausea can be transient, the questionnaire included variables to estimate nausea burden: nausea pattern (varying or constant), occurrence of vomiting, and ability to eat or drink. These parameters

correspond to the PONV Intensity Scale, developed by Wengritzky *et al.* to capture severe PONV.[113] During the development of this score (which was later found to be too complex for routine use),[152] a visual analogue scale was also used and found comparably easy to both manage and understand by investigators and patients. Although the NRS has not been validated for nausea, its straightforward format was considered similarly easy for patients to use when evaluating symptom intensity over time, and use of the same measurement scale for both symptoms would facilitate patient recognition.

Statistical analysis, Papers I–II

The power calculation and statistical plan for *Papers I and II* were developed in collaboration with independent statistician Mats Fredriksson at Forum Östergötland. Statistical analyses were performed by the first author using IBM® SPSS® Statistics 23.0 and 26.0 IBM SPSS Statistics (IBM Corp., Armonk, NY) and interpreted together with senior author Ellen Andersson.

Categorical variables were presented as numbers and percentages, while continuous data were presented as medians with interquartile ranges (IQR). Statistical significance was defined as $P < .05$.

Power calculation

Previous studies provided estimates of mean pain scores and variability required for sample size estimation but were based on relatively small cohorts (50–53 patients per treatment arm), limiting reliable assessment of distributional assumptions.[26,148] Therefore, although clinically relevant treatment effects were defined using mean differences, the Wilcoxon Mann–Whitney U test was chosen for both power calculation and analysis to provide robust inference without assuming normality of NRS score distributions.

A clinically relevant difference in pain intensity was defined as 2 points on the numeric rating scale. Based on previous studies by Tsai

et al., a standard deviation of 3.5 points was assumed.[26,148] Using a two-tailed alpha of .05 and a power of 90%, the required sample size was calculated to be 69 participants per group.

To account for loss to follow-up, 100 participants per group were included in *Paper I* (including both LRYGB and LSG). Due to an unexpected logistical loss to follow-up in *Paper II*, related to a reorganization of postoperative patient care during the study period, an amendment to include additional participants was granted by the Regional Ethical Review Board, resulting in a total of 130 randomized participants in each group.

Statistical methods

The chi-square test was used for comparison of categorical, binomial data. Pain and nausea scores were compared using the Mann–Whitney U test, as NRS scores are ordinal and may not follow a normal distribution. In *Paper I*, duration of surgery and length of hospital stay were compared using a two-sample *t*-test. Given the sample size of more than 50 participants per group, the test was considered robust to moderate deviations from normality. In *Paper II*, the Mann–Whitney U test was used for all continuous variables for methodological consistency. Changes in pain intensity over time were analyzed using repeated-measures analysis of variance (ANOVA).

Papers III and IV

Registries that audit and provide feedback are recognized as important instruments for quality improvement.[71,153] Sweden is well known for its medical quality registries, based on personal IDs, which enable the production of high-quality research papers in different areas. SOReg and GallRiks (presented previously) are no exceptions, providing yearly reports depicting performance and variation thereof. This variation in performance is the very core of *Papers III–IV*, as it may reflect modifiable differences in clinical practice. The awareness of this variation entails an ethical obligation to analyze the figures and potentially clarify whether there is room for improvement.[154]

Benchmarking

Traditional outcome reporting generally reflects average performance across a population and therefore offers limited insight into what may be achievable under standardized clinical conditions. Benchmarking is a methodological approach designed to identify best achievable outcomes, that can function as targets for quality improvement initiatives. In recent years, benchmarking has received growing attention within surgical research and practice.[155-159] *Papers III* and *IV* sought to define benchmarks for bariatric surgery and elective cholecystectomy, respectively, aiming at system-level improvement through individual surgical facilities' subsequent identification of performance gaps and elaboration of enhancement strategies.

Benchmarking methodology

There are two prevailing benchmarking methodologies used within the surgical field: the "*Best Patient in Best Center"* methodology (BPBC); and the *Achievable Benchmark of Care* methodology (ABC™).[160,161]

The BPBC methodology establishes outcomes in low-risk patients treated at high-volume expert centers, whereas the ABC™ methodology derives empirically achievable benchmarks from

unselected real-world cohorts using statistical ranking methods. The former emphasizes optimal achievable performance under ideal conditions, whereas the latter focuses on attainable excellence within routine clinical practice.

An advantage of the BPBC methodology is the limitation of confounding through case mix, as only low-risk, well-defined patients are included. However, this minimizes generalizability of the results to real-world practice – an advantage of the ABC™ methodology. Additionally, the BPBC methodology bases the benchmarks on centers of excellence, spanning a minimum of three different continents. This makes it sensitive to selection bias concerning centers, and less suitable for continuous quality monitoring.

Both methodologies aim to establish best possible, but also achievable outcomes. For negative outcomes, the BPBC methodology sets the benchmark cut-off at the 75th percentile of the median values, meaning that three-quarters of the benchmark centers have median values at or below this threshold.[160] A Delphi consensus paper treating this specific methodology, described that cohort morbidity below this value ought to be considered acceptable.[162]

Given the high-quality Swedish registries, the ABC™ methodology seemed suitable for nationwide benchmarking. The methodology is based on the concept of the "pared mean", whereby benchmark levels are defined as the average result of top performing facilities.[161,163] To mitigate the influence of random variation associated with small case volumes and reward consistent performance, facilities are ranked using Bayesian volume-adjusted estimates. For each facility, an "adjusted performance fraction" is calculated for the chosen indicator: (number of events + 1) / (number of procedures + 2). For adverse outcomes, a *lower* adjusted fraction indicates better performance, whereas for positive outcomes, the opposite applies. Facilities are then ranked according to their adjusted performance, and the highest-performing facilities are sequentially included in a pared cohort until at least 10% of the total study population is

represented. The mean outcome of this cohort constitutes the benchmark value for the indicator under study.

Bariatric surgery had previously been benchmarked using the BPBC methodology, providing an opportunity to explore whether application of the ABC™ methodology would yield different benchmark targets.[157] In contrast, although numerous studies had reported outcomes after cholecystectomy, comparisons were hampered by heterogeneity between cohorts, and, to our knowledge, no standardized benchmarks had previously been established.

Adjustment for risk and case mix

Four criteria should be met for the ABC™ methodology to have sufficient internal validity when comparing outcomes:

1) *Good data quality*

In *Paper III*, the participant inclusion period started in January 2012, as all surgical facilities performing bariatric surgery in Sweden reported to SOReg by that time. In *Paper IV*, the inclusion period started in January 2015, since a major revision of registry variables had been undertaken at that time. Inclusion ended in December 2021 for the bariatric cohort, and in 2023 for the subsequently analyzed cholecystectomy cohort.

To minimize reporting bias a prerequisite for outcome variables was ≥90% reported data. Facilities with ≥5% of missing data were excluded from contributing to the benchmark cohort. Additionally, facilities with zero adverse events or zero postoperative complications were excluded from benchmark contributions.

2) *Case mix adjustment*

Inclusion criteria were adults ≥18 years and primary, elective surgery with benign indication. Exclusion criteria were patients undergoing concomitant procedures, robotic surgery, and patients with missing data concerning the surgery.

In *Paper III*, patients with previous anti-reflux surgery were excluded, whereas in *Paper IV,* patients with a history of major upper abdominal surgery were excluded. These variables were found in the respective registries. Furthermore, patients with preoperatively detected CBD stones or abnormal IOCs were excluded from the cholecystectomy cohort, to avoid influence on outcomes from follow-up procedures, such as ERCP. For the same reason, patients without an IOC were also excluded from participation. As IOC is routine in Sweden, this was not expected to substantially affect the representativeness of the benchmarks.[66,67]

Streamlining the surgical interventions as much as possible, the cohorts' case mixes were assumed to be reflected by the participants' preoperative health conditions. These were classified according to ASA in the cholecystectomy cohort, and according to OS-MRS in the bariatric cohort.

3) Relevant outcomes

In both *Papers III–IV*, clinically relevant outcome measures were based on database variables reflecting surgical challenges and postoperative complications. Intraoperatively they were conversion to open surgery; adverse events; closing of mesenteric openings in LRYGB; and intraabdominal drain placement in the cholecystectomy cohort. Postoperative variables to benchmark were complications; reoperations; readmissions; length of hospital stay (LOS); follow-up, and time to follow-up in *Paper III*; whereas bile leakage and a composite benchmark of postoperative interventions (comprising blood transfusion, percutaneous drainage, ERCP, or reoperation) were included in *Paper IV*.

Concerning intraoperative events, different categorizations were applied. In *Paper III*, intraoperative adverse events were categorized according to the refined Satava classification[92,93] combined with the ClassIntra classification category IV[95], to allow inclusion of identified severe adverse events (Table 2). Satava II–III were assumed less subject to registration bias compared to Satava I and therefore

benchmarked separately. In *Paper IV*, only severe adverse events were benchmarked, defined as intestinal perforation, bile leakage (due to e.g. CBD injury), or bleeding requiring conversion to open surgery or blood transfusion.

Regarding postoperative complications, SOReg contains a specific CD variable. In *Paper IV* on the other hand, the CD classification of postoperative complications had to be constructed from predefined registry variables concerning postoperative treatment and supplemented by free-text entries.[97]

Severe postoperative complications constituted the main outcome in both studies, as they represent a clinically relevant and comparable endpoint across procedures. The remaining benchmarks contextualize, support, or contradict the severe complication benchmark and aid interpretation of institutional performance. In both *Papers III–IV*, severe postoperative complications were defined as CD ≥III, assessed within 30 days after surgery.

The CCI was outside the scope of *Papers III–IV*, as it has not been implemented in SOReg and was only recently introduced in GallRiks.

4) *Risk adjustment*

To facilitate future risk prediction, improve comparability between providers, and reduce the risk of facility risk aversion, the benchmark for severe postoperative complications was adjusted for preoperative risk factors. Candidate covariates were selected based on the ACS NSQIP (The American College of Surgeons National Surgical Quality Improvement Program®) Surgical Risk Calculator and procedure-specific evidence identifying independent predictors of major complications after laparoscopic bariatric surgery and cholecystectomy, including age, sex, and comorbidity burden.[116,119,145,164-166] Separate benchmarks were developed for patient groups defined by individual preoperative risk factors.

Statistical analysis, Papers III–IV

The statistical plan for *Papers III* and *IV* was discussed with an independent statistician at Forum Östergötland. Statistical analyses were performed by the author using IBM® SPSS® Statistics version 29.0.0.0 (IBM Corp., Armonk, NY, USA). Results were interpreted together with the co-authors of the respective studies.

Descriptive data were presented as numbers and percentages or median with IQR, as appropriate. Risk factors for severe complications were evaluated using univariable and multivariable binary logistic regression analyses. Statistical significance was defined as $P < .05$.

ETHICAL CONSIDERATIONS

Medical decision-making and clinical research are commonly guided by four fundamental bioethical principles: *autonomy, beneficence, non-maleficence, and justice*, as described by Beauchamp and Childress.[167,168]

These principles are reflected in the *Declaration of Helsinki*, developed by the World Medical Association in 1964, and continuously revised thereafter. [154] The declaration provides ethical guidance for research involving human participants or identifiable human data.

Papers I–IV were conducted in accordance with the Declaration of Helsinki and applicable national legislation governing research involving human subjects. The specific concerns related to the studies are described below.

Consequences of PRM

Prior to ethical approval, the PRM was evaluated with regard to potential risks and anticipated benefits.

Beneficence: Present and future patients could benefit from the trial if PRM proved useful in reducing postoperative pain or nausea. Participants might also benefit from participation through structured perioperative follow-up and optimized clinical attention characteristic of prospective trials.

Non-maleficence: Participants could potentially experience harm, although adverse effects were not anticipated. Previous studies investigating PRM in ASA I–II patients had not reported any harmful consequences. In *Papers I–II* the maneuver was performed on patients categorized as ASA I–II, including patients with a BMI ≥40 kg/m^2 (ASA III).

At the time of study initiation, manual PRM was already routinely applied intraoperatively in the bariatric surgery population, based on evidence demonstrating improved postoperative pulmonary function.[169] Consequently, incorporation of the maneuver into a randomized study represented minimal additional risk compared with standard clinical practice.

The theoretical risk related to transiently elevated airway pressure was considered limited. Physiological airway pressures generated during coughing or sneezing may exceed 100 cm H_2O.[170] That is substantially higher than pressures applied during controlled PRMs, supporting the assessment of low intervention-related risk.[150] Continuous anesthetic monitoring further minimized potential harm.

Justice: If perioperative interventions have the potential to improve patient outcomes, the medical profession has an ethical obligation to evaluate them scientifically. It would be unjust to deny patients potentially beneficial treatment. Further, it is fair to evaluate an unproven procedure scientifically before introduction in clinical practice.

Conclusion: The anticipated benefits of PRM were considered to outweigh the theoretical risks, and no major ethical concerns were identified prior to study initiation.

Benchmarking

Beneficence: *Papers III–IV* were retrospective registry studies. Although there was no benefit to patients treated in the past, future patients may benefit from practice assessment and accompanying quality improvement initiatives.[171,172] Article 5 in the Declaration of Helsinki states: "Even well-proven interventions should be evaluated continually through research for their safety, effectiveness, efficiency, accessibility, and quality."[154] The establishment of reference values for common surgical procedures, with emphasis on patient safety, aligns with this ethical responsibility of evaluation and improvement.

Non-maleficence: Care was taken to present aggregated and anonymized data to minimize institutional harm to participating surgical facilities. There is a theoretical risk that benchmark results may be interpreted in a punitive manner when applied outside the research context. Performance comparisons may influence healthcare systems, reimbursement structures, or institutional reputation. If benchmarks are interpreted without adequate risk adjustment, surgical units managing complex patients could appear to perform worse, potentially creating incentives for risk avoidance or rejection of high-risk cases.[173,174] To minimize this risk, benchmarks in the present studies focused on clinically meaningful outcomes, excluded participants with anticipated surgical complexity, and included risk-adjustment for severe complications.

Justice: The studies' nationwide populations were unselected, ensuring equitable representation and maximizing generalizability.

Conclusion: Taken together, the intended societal and patient benefits were considered to outweigh the theoretical risks to individual surgical facilities.

Participant autonomy and informed consent

In *Papers I* and *II,* participants received written and oral information regarding study participation, including the possibility to withdraw at any time without consequences for clinical care. Only patients competent to make decisions and with the ability to understand the Swedish language were included. Written consent was required, thereby ensuring respect for patient autonomy.

Papers III and IV were retrospective registry studies. Since patients were informed of their participation in the registries and their right to opt out, informed consent was not required for these studies. All participant data received were pseudonymized.

Data management and confidentiality

Protection of patient integrity is closely related to the principles of autonomy and non-maleficence – *primum non nocere*.

Papers I and II

Participants provided written consent and completed a preoperative questionnaire including demographic and clinical data. Intraoperative and postoperative variables were recorded by clinical staff. Patient-reported outcomes regarding pain and nausea were collected using standardized questionnaires. All physical study documents are stored in the archives of Linköping University Hospital for 15 years according to institutional regulations, after which they will be destroyed.

Data were pseudonymized using study randomization numbers as identification. Digital databases consisting of Excel® and IBM SPSS® files are stored in the Linköping University secure cloud for 15 years and will thereafter be deleted. Data may be available upon reasonable request during the data retention period.

Papers III and IV

For *Papers III* and *IV*, pseudonymized datasets were obtained from the national quality registries SOReg and GallRiks. The resulting Excel® and IBM SPSS® files are stored in the Linköping University secure cloud under the same policy as mentioned above.

Ethical approval

Papers I and *II* received approval by the Regional Ethical Review Board in Linköping (Dnr 2014/120-31; amendment Dnr 2018/2-32). Ethical approval for *Papers III* and *IV* was granted by the Swedish Ethical Review Authority (Dnr 2022-04311-01; amendment Dnr 2024-06020-02).

MAIN FINDINGS

Flow charts of inclusion and detailed descriptive characteristics are presented in the individual papers, while key findings of *Papers I–IV* are outlined below.

Part I — Effects of Pulmonary Recruitment Maneuver

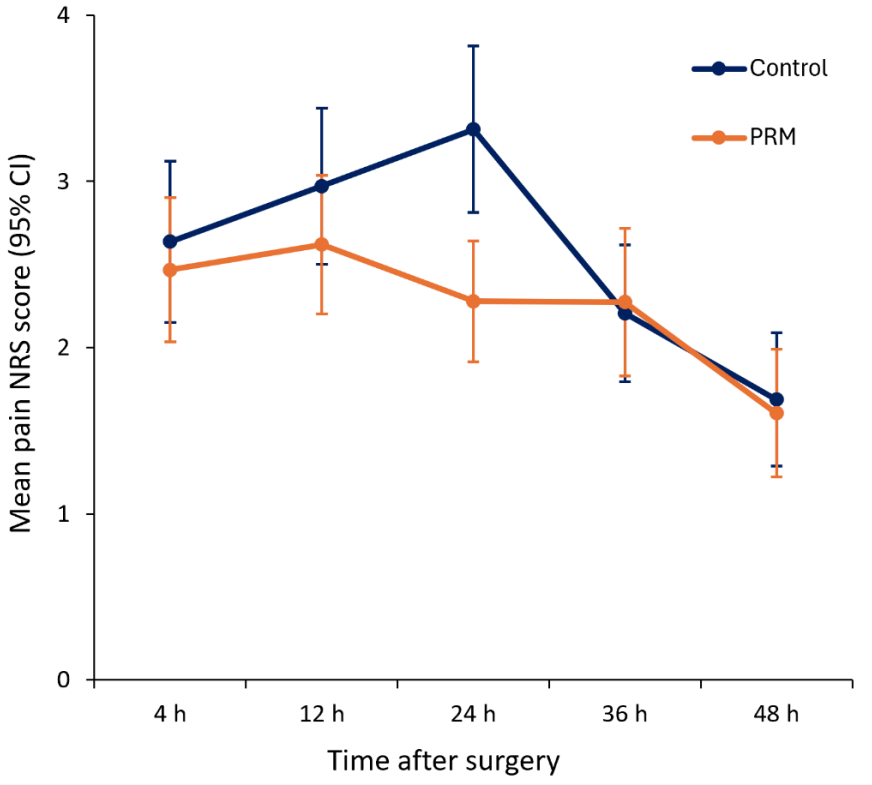
Baseline demographic and clinical characteristics were similar between the intervention and control groups. Harmful effects of the intervention were not observed in either study.

Reduced overall postoperative pain (Paper I)

In the bariatric surgery cohort, there were 150 participants with questionnaires available for analysis (79 PRM, 71 controls). Pain was experienced by 91% of the participants, with no difference between groups. The main outcome, pain intensity, peaked at 24 hours in the control group and was higher than in the PRM group at that time point (median NRS score 3 (IQR 2–5) vs. 2 (IQR 1–3), $P = .002$). In contrast, pain intensity in the PRM group remained stable before declining. There was a significant difference in evolution of pain intensity during the first 24 hours postoperatively, in favor of the group receiving PRM ($P = .045$) (Figure 8). The finding was supported by higher opioid requirements in the control group (9 mg (IQR 5–15) vs. 5 mg (IQR 2–10) IV morphine equivalents, $P = .025$).

Both the incidence and intensity of nausea peaked 4 hours after surgery, when it was experienced by 57% of the patients, with a median NRS score of 1 (IQR 0–3) in both groups. Vomiting occurred in approximately 10% of the patients.

Figure 8. Evolution of pain intensity after bariatric surgery



The pain trajectory during the first 24 hours differed significantly between the groups (P = .045, ANOVA), as did NRS score at 24 hours after surgery (P = .002, Mann–Whitney U-test). PRM, pulmonary recruitment maneuver. NRS, numeric rating scale.

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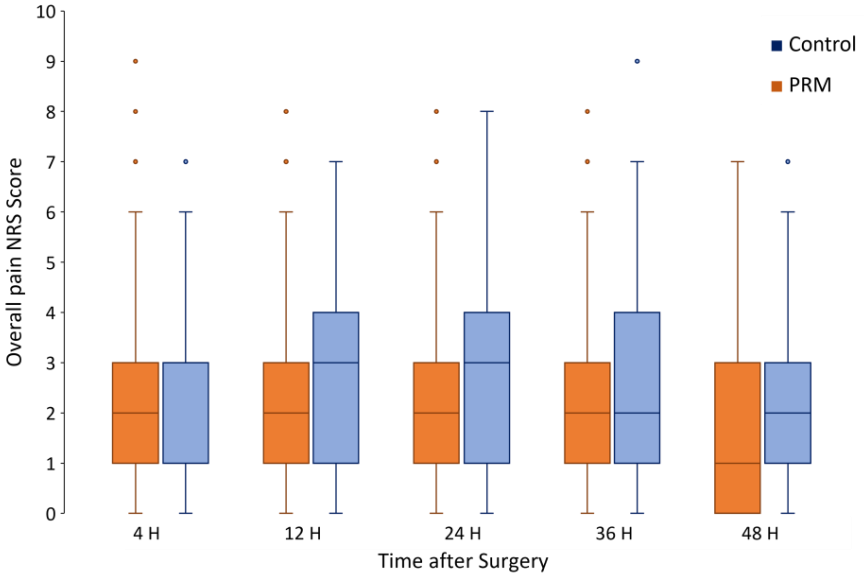
Reduced incidence of shoulder pain and nausea (Paper II)

In the cholecystectomy cohort, there were 147 participants with questionnaires available for analysis (76 PRM, 71 controls). Nearly all participants experienced postoperative pain. There was no difference in overall pain intensity at any time point, nor in pain trajectory (P = .739). Visually, evaluating median NRS scores and IQR, a trend in favor of PRM could be seen (Figure 9). The control group received nonsteroidal anti-inflammatory drugs (NSAID) more frequently than the PRM group (9.9% versus 1.3%, P = .023), but opioid consumption did not differ between groups.

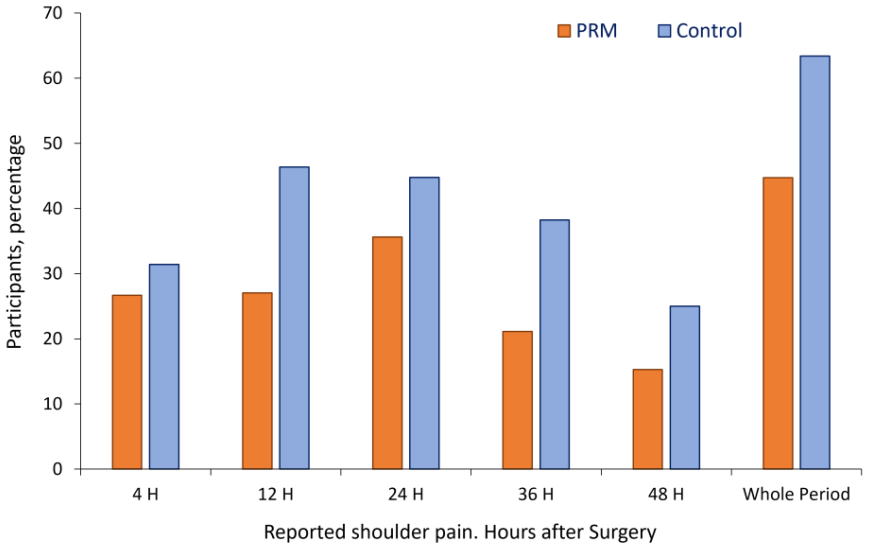
Figure 9. Overall pain intensity, expressed as median value (IQR)



Overall pain intensity did not differ significantly between the PRM and control group on any occasion, though there was a trend in favor of the PRM group. The control group median at 4 hours was NRS score 3. Boxes represent the interquartile range (IQR), the horizontal line indicates the median, whiskers extend to the most extreme non-outlying observations (Tukey definition), and circles indicate outliers (>1.5 × IQR). PRM, pulmonary recruitment maneuver. NRS, numeric rating scale.

Shoulder pain incidence was lower in the PRM group (45% versus 63%, P = .023) (Figure 10). The number needed to treat (NNT) was 6 (95% CI 2.9–35.5).

Figure 10. Shoulder pain incidence

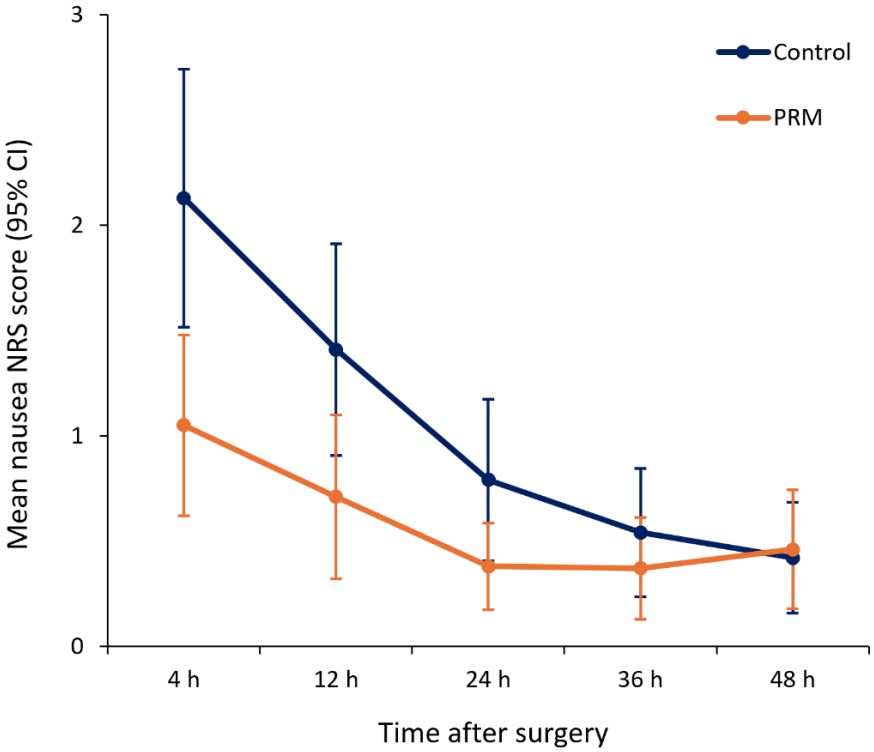


Shoulder pain incidence differed significantly between the PRM and control group during the 48-hour period after surgery (P = .023). The incidence was specifically different at 12 (P = .016) and 36 hours (P = .027). Analysis: χ^2 test. PRM, pulmonary recruitment maneuver.

Further, the incidence of nausea was lower in the PRM group (51% versus 70%, P = .018), with an NNT of 6 (95% CI 2.9–27.4). Despite low intensity scores in both groups, there was a difference in evolution of nausea intensity during the 48 hours after surgery, in favor of the group receiving PRM (P = .025) (Figure 11). The difference was supported by more participants in the control group requiring antiemetics (42% versus 25%, P = .027), and that the required dose per participant was slightly higher (0 mg (IQR 0–4.0) vs. 0 mg (IQR

0–1.5), P = .015). When the dose was adjusted for administered nausea prophylaxis with ondansetron, the difference between the groups was even greater (P = .003). There was also a difference in mobilization, with a higher proportion of patients having been out of bed in the PRM group 4 hours after surgery (94.5% vs. 82.6%, P = .025).

Figure 11. Evolution of nausea intensity after cholecystectomy



Nausea intensity differed significantly between the groups during the 48 postoperative hours, P = .025 (ANOVA). NRS score differed specifically at 4 (P = .006) and 12 hours after surgery (P = .015), analyzed with Mann–Whitney U test. PRM = pulmonary recruitment maneuver.

Part II — Benchmarking

In total, *Paper III* defined 12 benchmarks for LRYGB and 10 benchmarks for LSG, while *Paper IV* defined 10 benchmarks for ELC. Although several perioperative process and outcome indicators were benchmarked, severe postoperative complications (CD ≥III) were the main outcome in both studies. All benchmark values are presented in Table 1 in each of *Papers III* and *IV* (see appended articles).

Cohort characteristics

Paper III included 36 846 patients undergoing LRYGB at 53 surgical facilities and 15 246 patients undergoing LSG at 48 facilities between 2012 and 2021. *Paper IV* included 48 564 patients undergoing ELC at 81 surgical facilities between 2015 and 2023. Biliary colic was the most common indication for ELC (median 76%, IQR 65–85%), followed by gallstone-related complications (median 23%, IQR 15–32%), whereas gallbladder polyp accounted for merely 1.1% of cases. All three cohorts represented nationwide clinical practice and consisted predominantly of middle-aged, low-risk patients (OS-MRS class A and ASA I–II respectively).

Perioperative benchmarks

Serious intraoperative adverse events were rare across all three cohorts. Conversion to open surgery was very rare in the bariatric cohorts (≤0.2%), where it was classified as Satava II and included in severe adverse events, although more common in ELC (1.3%), where the benchmark was 0.1%.

Hospital stay benchmarks were 1 day after bariatric surgery and same-day discharge after ELC, corresponding to the median value in each cohort. In the bariatric cohorts, benchmark values for postoperative follow-up exceeded 99%, and follow-up was performed within one week of the recommended six-week target.

Provider-level performance variation differed between procedures. The widest variation was observed for LSG, intermediate variation for LRYGB, and the narrowest variation for ELC.

Severe postoperative complications

The incidence of severe postoperative complications was highest after LRYGB (3.6%), followed by LSG (1.9%) and ELC (1.7%). Corresponding ABC™ benchmarks are presented in Table 7.

Facility-level variation in severe postoperative complications was evident in both bariatric procedures, particularly after LSG. Benchmarks for severe postoperative complications closely paralleled those for reoperation in both bariatric cohorts, where intestinal obstruction after LRYGB and postoperative bleeding after LSG were the most frequent indications for reoperation.

In the ELC cohort, the rate of severe postoperative complications differed approximately twofold between the upper and lower performance quartiles, although the absolute difference was only 1.2 percentage points, Table 7. The ELC benchmark for severe postoperative complications was 1.0%, corresponding to the upper quartile of overall cohort performance. Bile leakage occurred in 0.6% of patients, of which only a small proportion was attributed to severe CBD injury. Unlike the bariatric cohorts, many severe complications after ELC were managed by non-surgical interventions, as reflected by the reoperation benchmark being only a tenth that of the complications benchmark.

Table 7. Severe postoperative complications and reoperations

Surgery	Outcome	Total cohort rate	25th percentile rank	Median	75th percentile rank	ABC
LRYGB	Severe postoperative complication (%)	3.6	5.1	3.8	2.5	**1.5**
LRYGB	Reoperation (%)	3.1	4.4	3.0	2.3	**1.3**
LSG	Severe postoperative complication (%)	1.9	3.7	1.8	0.5	**0.4**
LSG	Reoperation (%)	1.5	2.8	1.3	0.4	**0.4**
ELC	Severe postoperative complication (%)	1.7	2.2	1.6	1.0	**1.0**
ELC	Reoperation (%)	0.7	0.9	0.5	0.2	**0.1**

The table displays two tangible indicators: severe postoperative complications and reoperation. Percentiles represent facility-level performance ranks where a higher percentile equals better performance (lower complication rate).

LRYGB, laparoscopic Roux-en-Y gastric bypass. LSG, laparoscopic sleeve gastrectomy. ELC, elective laparoscopic cholecystectomy.

Risk adjustment and subgroup benchmarks

Risk factors for severe postoperative complications differed between procedures. After LRYGB, previous thromboembolism and ongoing antidepressive treatment were independently associated with severe complications, whereas age, BMI, smoking, dyspepsia, and diabetes were independent predictors after LSG. In the ELC cohort, ASA ≥III and previous abdominal surgery were identified as independent preoperative risk factors. Intraoperative finding of inflammation, interpreted as a marker of operative complexity, was also identified as a risk factor.

Risk adjustment had limited influence on benchmark values. Among the evaluated bariatric subgroups, only diabetes in the LSG cohort increased the adjusted benchmark for severe postoperative complications, from 0.4% to 1.2%. In the ELC cohort, ASA ≥III increased the corresponding benchmark from 1.0% to 1.5%. In low-risk subgroup analyses of ELC, benchmark values for severe postoperative complications were 0.6% for patients with ASA ≤II and no intraoperative inflammation and 0.7% for patients with ASA ≤II undergoing surgery for biliary colic or gallbladder polyp.

DISCUSSION

The four papers included in this thesis addressed the aim to improve outcomes after laparoscopic upper abdominal surgery in two different ways, as illustrated in Figure 12. *Papers I* and *II* sought causal evidence by evaluating a specific intraoperative intervention, PRM, whereas *Papers III* and *IV* aimed to support system-level improvement by defining benchmarks. *Papers I* and *III* aimed to improve outcomes of bariatric surgery, while *Papers II* and *IV* addressed outcomes of elective cholecystectomy. Together, these approaches provide complementary perspectives on perioperative improvement for these procedures.

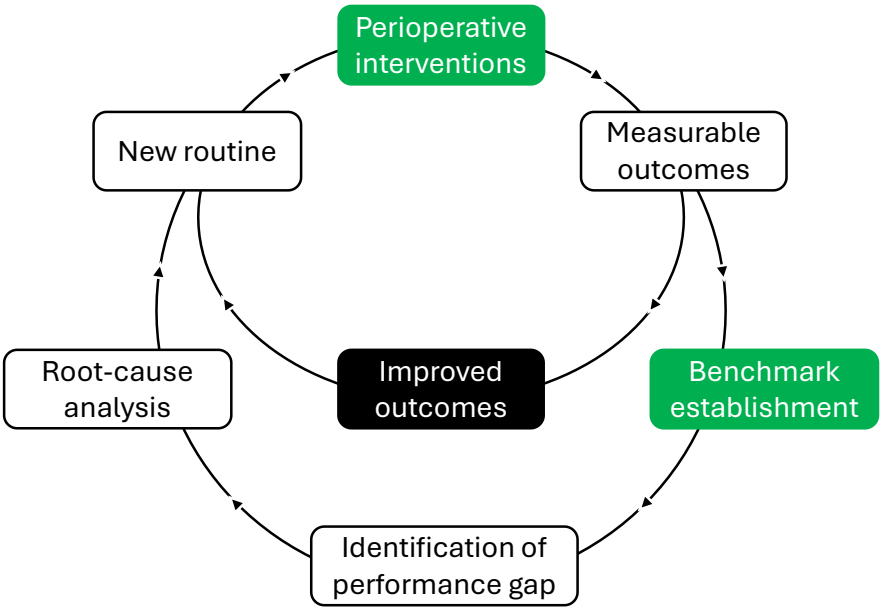


Figure 12. The contribution of the thesis illustrated within two interwoven cycles of perioperative quality improvement.
Inner cycle: Papers I–II; outer cycle: Papers III–IV.

Papers I and II

In both trials, the PRM demonstrated beneficial effects on postoperative pain. In *Paper I*, PRM reduced overall pain intensity; in *Paper II*, it reduced the incidence of shoulder pain, although overall pain intensity did not differ. The findings in *Paper I* were supported by lower postoperative opioid requirements, while NSAID consumption was lower in *Paper II*.

The results were consistent with those in previous studies.[26,38,147-149] Subsequent meta-analyses published after completion of *Papers I–II* have reported reductions in postoperative shoulder pain after a PRM of 40 cm H_2O, supporting the direction of the present findings.[175,176] Several RCTs have demonstrated favorable results concerning incidence and intensity of shoulder and abdominal pain applying PRM in patients undergoing cholecystectomy.[34,177-179] Noh *et al.* also noticed significantly reduced abdominal pain intensity during mobilization during the first 24 hours after surgery.[177]

In *Paper II*, patients in the PRM group experienced less nausea, reduced need for antiemetics, and earlier mobilization. Since its publication, two additional studies evaluating PRM during ELC have reported conflicting findings. Hosseinpour *et al.* observed significantly less vomiting following PRM, whereas Noh *et al.* found no difference in the incidence or severity of PONV.[177,179] The mechanism underlying any potential effect of PRM on postoperative nausea remains uncertain. Given the multifactorial etiology of PONV, any association between PRM and reduced nausea may be indirect, potentially reflecting reduced postoperative pain and improved recovery rather than a direct physiological effect of the maneuver itself.

Although the observed median difference in overall pain in the bariatric cohort was smaller than the predefined clinically relevant mean difference used for sample size estimation (1 versus 2 points), pain intensity remained relatively stable over time in the intervention

group, whereas pain increased in the control group, resulting in a statistically significant between-group difference at 24 hours after surgery. Previous studies investigating the minimal clinically important difference in pain intensity have found that a 10-mm reduction on a VAS or a 1–1.3-point reduction on an NRS may be clinically relevant.[109,110,180] Unfortunately, pain intensity was not assessed during movement, when a greater effect might have been observed.

PRM did not significantly reduce overall pain, the main outcome, in the cholecystectomy cohort; but when examining the pain trajectory over time, both cohorts displayed the same trend: pain intensity in the PRM groups remained stable and then fell, while pain intensity in the control groups remained higher through 24 hours after surgery. Although the median value was consistently 1 point lower in the intervention group during the first 24 hours in the cholecystectomy cohort, the variability within the groups resulted in overlapping distributions, and the difference did not reach statistical significance.

Retrospectively, it would have been interesting to include a separate NRS for evaluation of shoulder pain intensity in the questionnaires, as shoulder pain is particularly associated with pneumoperitoneum, and the incidence of shoulder pain was lower in the cholecystectomy cohort receiving PRM. This was not considered at the initiation of the studies, mostly since shoulder pain had been the focus of most previous studies, which called for complementary research evaluating overall pain, but also to avoid loss to follow-up due to extensive postoperative questionnaires.

The PRM leads to increased intrathoracic pressure, which may cause an elevated central venous pressure (CVP) together with increased pulmonary vascular resistance and pulmonary artery pressure, increasing the right ventricle's preload and afterload.[181] A temporary decrease in the right and left ventricular ejection fraction may ensue, with subsequent effects on heart rate and blood pressure.[181] The inflation could potentially cause pulmonary overexpansion, leading to

pneumothorax or pneumomediastinum. In *Papers I–II*, no adverse effects of PRM were observed. Noh *et al.* reproduced an RCT applying a ventilator-piloted PRM in a cholecystectomy cohort, with a maximum airway pressure of 40 cm H_2O.[177] They applied a stepwise recruitment maneuver (in *Papers I–II* it was sustained) and observed one patient with pronounced hypotension, needing pharmacological remedy.[177] A meta-analysis by Pei *et al.*, analyzing the effect of recruitment maneuvers on postoperative pulmonary complications after laparoscopic abdominal surgery (favorable effect), did not observe any significant difference in mean arterial pressure between intervention and control groups concerning the 2 177 patients where this was registered, but concluded that further well-conducted studies regarding hemodynamic influence were needed.[181]

Even if PRM appears to be safe, its potential hemodynamic effects underscore the importance of close monitoring during the maneuver. As specified in the PRM protocol used in *Papers I and II*, patients should be hemodynamically stable before the maneuver is performed, and the maneuver should be discontinued if hypotension occurs.

Strengths

A particular strength was the standardized administration of the PRM using a predefined ventilator protocol, a feature that had not previously been reported. This ensured equal airway pressure for all participants while allowing individualized inspiratory volumes.

Another strength was the blinding of participants, postoperative staff and investigators. Pain assessment is inherently subjective and therefore vulnerable to reporting bias. However, blinding of participants and staff likely reduced this risk. The randomization performance was kept secret from the investigator registering the participants' data until the end of the study, limiting measurement bias. Furthermore, randomization had achieved groups with comparable demographic data.

Although perioperative management inevitably varied somewhat between the multiple surgeons, anesthesiology staff members, and other healthcare personnel being part of the studies, such variability was not thought to be systematic, but to reflect routine clinical practice and therefore strengthen external validity.

Finally, an important strength was the concordance between subjective symptom ratings and objective surrogate measures, as lower pain scores were accompanied by reduced opioid requirements in *Paper I*, while the lower incidence of shoulder pain and reduced nausea scores in *Paper II* were accompanied by lower NSAID and antiemetic use, respectively.

Limitations

Excluding participants with events likely to influence postoperative pain after randomization was predetermined but resulted in a per-protocol rather than a strict intention-to-treat analysis. Further, post-randomization exclusions may introduce selection bias, as randomization no longer fully guarantees comparable groups. Consequently, some reduction in internal validity may be considered when interpreting the findings. Exclusions due to extensive surgery or complications were few and similarly distributed between groups though, making substantial influence on the results unlikely. Nevertheless, a full intention-to-treat analysis demonstrating similar findings would have strengthened the robustness and generalizability of the results.

Another limitation is the single-center design, limiting the generalizability of the results. However, PRM had not previously been tested in a population of solely upper abdominal surgery, where patient positioning and hence the effects of pneumoperitoneum differed from those of pelvic surgery. It was therefore justifiable to perform a single-center trial, where the intervention conditions could be better controlled.

The rather large proportion of patients with missing questionnaires in *Paper II* entailed a risk of attrition bias. However, patients with missing questionnaires were similarly distributed between the groups, and the subsequent non-response analysis identified only a shorter operative time in the missing group. A likely explanation for the missing questionnaires was the closure of the fast-track postoperative ward, which resulted in patients being transferred to another ward, where it took time to fully implement the postoperative study protocol, including distribution of questionnaires.

Finally, as several parameters related to pain and nausea were analyzed in *Paper II*, the risk of type I error due to multiple testing should be acknowledged. Thus, statistically significant findings among these analyses may have occurred by chance and warrant some caution in interpretation. Although the parameters assessed were included in the study questionnaire from the outset, this does not eliminate the risk associated with multiple testing. Nevertheless, the findings across related outcomes were broadly consistent with a beneficial effect of PRM.

Papers III and IV

Overall, the cohort-level rates in *Papers III–IV* for conversion to open surgery, postoperative complications, and reoperation were within the ranges reported in prior studies despite differences in case mix and endpoint definitions, supporting external validity (Tables 8 and 9).[89,182-187]

Table 8. Overview of studies analyzing outcomes (%) of bariatric surgery

	Paper III		Chaar [182]		Poelemeijer [183]		Singhal [184]	
	Sweden		USA		Europe*		Global	
Inclusion time	2012–2021		2015		2015–2017		2020	
Procedure	LRYGB	LSG	LRYGB	LSG	LRYGB	LSG	LRYGB	LSG
Intraoperative adverse event	3.3	1.4	NA	NA	2.3	1.6	NA	NA
Conversion to open surgery	0.2	0.0	NA	NA	NA	NA	NA	NA
Length of stay (median days)	1	1	2	2	1.6 mean	1.7 mean	NA	NA
Postoperative complications	7.5	4.7	NA	NA	5.7	5.3	8.0	5.8
Severe postoperative complications (CD ≥III)	3.6	1.9	NA	NA	2.6 CD ≥IIIb	2.4 CD ≥IIIb	2.7	2.2
Reoperation	3.1	1.5	2.5	1.0	2.0	2.1	1.5 CD IIIb	1.3 CD IIIb
Mortality	0.0	0.0	0.2	0.1	0.0	0.0	0	0.1

All numbers are percentages unless otherwise stated. Outcome definitions varied between studies. CD grade is presented when it influenced outcome reporting relative to other studies. Consequently, some caution is warranted when making direct comparisons between studies. *The study by Poelemeijer *et al*. included patients from the Swedish, Norwegian, and Dutch national registries; therefore, its data partly overlap with those in *Paper III*. NA, not available. CD, Clavien-Dindo.

Reoperation in the LRYGB cohort stood out as a slightly more common event in *Paper III* than in other studies (3.1% vs. 1.5–2.5%)[182-184]. A possible explanation may be that cohort inclusion commenced before Stenberg *et al.* demonstrated that closing mesenteric openings reduced long-term incidence of reoperation due

to internal herniation.[76] That same study noted an increased short-term risk of reoperation due to kinking of the jejunojejunostomy after mesenteric suturing, a risk higher than in other reports on mesenteric closure. Thus, the relatively high frequency of reoperation in *Paper III* might reflect a learning curve in mesenteric suturing. Current SOReg data provide some support for this explanation, as the average Swedish incidence of short-term reoperation has decreased gradually to 2.5% in 2025.[56] However, this hypothesis is not supported by the data from *Paper III*. When the cohort was stratified by surgery before and after 2016, no statistically significant difference in reoperation rates was observed (3.2% (818/25 392) vs 3.0% (313/10 502), P = .234, χ^2 test (data missing: 952 patients)). Another potential explanation could be differences in registration, as negative diagnostic laparoscopies are included in the Swedish material.

The higher severe complication and reoperation benchmarks for LRYGB, relative to LSG and ELC, may reflect a greater technical and physiological complexity. Similarly, the slightly higher severe complication benchmark observed for ELC compared with LSG may be related to case mix and procedural context, as ELC is often performed in patients with a history of acute or chronic cholecystitis, which may increase technical difficulty.

The process benchmarks in *Papers III–IV*, which had narrow IQR variation, reflect standardized processes of care. LOS was short in both studies, and frequency of mesenteric closure; follow-up; and on-time follow-up was high in *Paper III*.

In *Paper IV,* several surgical facilities with varying case volumes contributed to benchmarks, whereas in *Paper III*, few high-volume facilities contributed to intraoperative benchmarks, and facilities with smaller case volumes potentially contributed to postoperative benchmarks. Univariable logistic regression analysis of case-volume in relation to risk for severe postoperative complications indicated that surgical facilities performing ≥100 LRYGB procedures annually were associated with lower odds (OR 0.7, 95% CI 0.6–0.8). The

association was not found in the LSG cohort. The inverse relationship between facility or surgeon LRYGB volume and lower postoperative complications has been demonstrated in previous Swedish and international studies, stimulating the discussion of suitable facility accreditation volume.[142,144,188] The *Paper III* results on the matter were not adjusted for other factors, and therefore no such recommendation could be made.

Table 9. Overview of studies analyzing outcomes (%) of ELC

	Paper IV	CholeS [185]	Lucocq [186]	Robocop [187]	Ambrose* [8]
	Sweden	UK/Ireland	UK	USA	Global
Inclusion time	2015–2023	2014	2015–2019	2020–2022	2022
Intraoperative adverse event	31 (0.5% severe)	~ 6.8	1.9	NA	NA
Conversion to open surgery	1.3	1.6	1.2	1.2	2.4
Length of stay (median days)	0 (0–1)	NA	NA	1 (1–2)	NA
Postoperative complication	5.1	7.7	4.9 CD ≥II	NA	6.4
Severe postoperative complications (CD ≥III)	1.7	NA	NA	NA	1.8
Reoperation	0.7	0.6	NA	NA	0.6 CD IIIb
Mortality	0.01	0.0	0.05	0.1	0.1

All numbers are percentages unless otherwise stated. Outcome definitions varied between studies. CD grade is presented when it influenced outcome reporting relative to other studies. Consequently, some caution is warranted when making direct comparisons between studies. *The numbers from the AMBROSE study represent the combined totals of the elective and delayed cholecystectomy groups. NA, not available. CD, Clavien-Dindo.

Across cohorts in *Papers III–IV*, the distance between population IQR values varied: there was a rather wide performance span for LSG, an intermediate variation in LRYGB performance, while the ELC performance span was tighter, with benchmark values close to routine practice. The wider performance variation in bariatric surgery indicates larger opportunities for optimization.

The narrow performance variation in ELC may reflect that laparoscopic cholecystectomy is a very common surgical procedure, mastered early in surgical training, technically relatively standardized and less complex than bariatric surgery. The biggest ELC performance differences encompassed placement of intraoperative drain, conversion to open surgery and readmission, likely to reflect differences in routines and decision-making between facilities and surgeons. Consequently, benchmark values in *Paper IV* may primarily identify refinement opportunities in perioperative decision-making rather than major differences in technical performance.

Interestingly, of the four bariatric benchmarks comparable to those previously reported by Gero *et al.*, those in *Paper III* were more stringent (Table 10).[157] Length-of-stay outcomes were more favourable in the Swedish cohort. For the other outcomes, median values were less favourable than the median of the centre-specific median values reported in the BPBC study. Nevertheless, the interquartile ranges in the Swedish cohort were narrow relative to the ranges of centre-specific medians reported in the BPBC study. Overall, the differences in benchmark stringency reflect the distinct methodologies.

Table 10. Comparable bariatric benchmark values

	Paper III, Sweden		Gero *et al.* [157]	
	BM (median; IQR)		BM (median; median range)	
Procedure	LRYGB	LSG	LRYGB	LSG
Length of stay (median days)	1 (1; 1–2)	1 (1; 1–2)	≤4 d (2; 1–5)	≤3 d (2; 1–5)
Postoperative complications (%)	3.6 (7.6; 5.4–9.9)	1.3 (5.4; 3.3–7.4)	≤9 (5.5; 0.3–17)	≤11 (3.7; 0–17)
Severe postoperative complications (%)	1.5 (3.8; 2.5–5.1)	0.4 (1.8; 0.5–3.7)	≤5 (2; 0–9.7)	≤5 (1.2; 0–7.1)
Reoperation (%)	1.3 (3.0; 2.3–4.4)	0.4 (1.3; 0.4–2.8)	≤2.5 (1.6; 0–4.2)	≤2 (1.1; 0–7.1)

BM, benchmark. LRYGB, laparoscopic Roux-en-Y gastric bypass. LSG, laparoscopic sleeve gastrectomy. IQR, interquartile range.

As several bariatric outcome studies have reported superior performance compared to previous BPBC benchmarks, the ABC™ methodology may be better suited to provide aspirational benchmarks in surgical procedures in resource-similar settings.[182-184]

An important aspect of benchmarking interpretation is that benchmark values should not be viewed as universally attainable minimum standards. Notably, facilities contributing to benchmark performance are seldom uniformly superior across different outcomes. Instead, benchmarks should serve as reference points for identifying clinically relevant performance gaps.

A limitation inherent in benchmarking, regardless of methodology, is that it does not provide the key to success. Instead, facilities must analyze their own results, and after comparing them with benchmarks, perform a root-cause analysis, implement change, and reevaluate. The Ishikawa fish bone diagram has been suggested as a suitable methodology to analyze causation in healthcare and has been tested against benchmarks for low anterior resection in rectal cancer.[172,189]

Strengths

The methodology used in *Papers III–IV* has several strengths. By using unselected nationwide cohorts and volume-adjusted benchmarking, the methodology reflects real-world clinical practice while promoting consistently superior results. The time frames of inclusion ensured benchmarks based on elevated performance over long periods of time, reducing the potential influence of random variation.

The use of validated, national quality registries with prospectively gathered data enabled inclusion of large, clinically representative patient populations, supporting external validity and reducing the risk of selection bias. Further, bias-mitigation rules were applied when deriving benchmarks, to reduce implausible underreporting

among benchmark setters, excluding facilities with ≥5% missing outcome data or facilities with "zero events" from contributing to benchmarks.

The ABC™ methodology offers a data-driven way to select providers with high performance, reducing selection bias. Importantly, the primary endpoint, severe postoperative complications, was risk-adjusted, counteracting the risk that benchmarks may cause facility risk aversion, excluding patient categories to enhance results. Additionally, benchmark values are based on routinely collected data, facilitating comparison and implementation on a national level, as every surgical facility has access to its results.

Limitations

Several limitations should be acknowledged. Registry-based studies are dependent on the validity and completeness of registered data, and although both registries have undergone validation, residual reporting bias and measurement error cannot be excluded. Differences in interpretation of registry definitions, completeness of data entry, and reporting practices between facilities may contribute to observed inter-facility variation in outcomes, independently of true differences in clinical performance.

Since risk adjustment was limited to variables recorded in the registries, residual confounding is possible. Potentially influential provider and facility factors, including surgeon experience, operating room staffing, and facility resources, were not evaluated. Participant characteristics, including ethnicity, socioeconomic status, and comorbidities not captured by the registries, were likewise unavailable for analysis.

Though care was taken to limit the surgical complexity, the lack of adjustment for patient comorbidity in the ranking process could reward a favorable case mix in facilities contributing to benchmark. Morbidity case mixes for benchmark cohorts are therefore presented

in *Papers III–IV*, and this should be taken into consideration when estimating the benchmark relevance to the individual surgical facility.

Some benchmarked outcomes, including intraoperative adverse events and postoperative bile leak, were uncommon. Consequently, small absolute differences in event counts may produce relatively large differences in observed rates, introducing statistical uncertainty into benchmark estimates. Although the ABC™ methodology reduces this limitation by deriving benchmarks from groups of high-performing facilities rather than individual facilities, some influence of random variation cannot be excluded. The large nationwide cohorts and prolonged inclusion periods likely reduced the influence of random variation.

In *Paper IV*, the severe postoperative complications outcome was a constructed variable derived from registry variables and supplemented by free-text, which could introduce misclassification bias if reporting differs between sites; the study implemented strict missing-data handling to mitigate this, but residual bias cannot be excluded.

Previously mentioned as a strength, the cohorts span multiple years, during which surgical techniques, perioperative processes, and registry reporting conditions may evolve. This could introduce temporal bias, if observed performance differences reflect practice change over time rather than persistent institutional performance. Benchmark values should therefore be regarded as dynamic rather than permanent targets and require regular renewal to remain clinically relevant.

Finally, the benchmarks were derived from outcomes in a single country with a high-resource healthcare system. Since benchmark values may be influenced by case mix, registry definitions, and healthcare context, their applicability to other settings should be interpreted with caution.

CONCLUSIONS AND CLINICAL IMPLICATIONS

Papers I and II

Papers I and *II* evaluated a pulmonary recruitment maneuver in laparoscopic upper abdominal surgery. Both trials showed favorable effects on postoperative pain when performing a PRM: on overall pain after bariatric surgery and on shoulder pain after cholecystectomy. Notably, beneficial effects were detected despite generally low postoperative pain intensity, suggesting that PRM may provide additive value even in settings with optimized perioperative care. Additionally, the cholecystectomy cohort receiving a PRM experienced less nausea. No adverse effects of the intervention were observed. Altogether, the findings support consideration of PRM in laparoscopic upper abdominal surgery for patients categorized as ASA I–II, including patients with BMI ≥40 kg/m^2.

Clinical implication

The ventilator-piloted PRM is simple, rapid, low-risk, requires no additional equipment, and can easily be integrated into routine clinical practice. The intervention has been implemented to ease postoperative pain after laparoscopic surgery at Vrinnevi Hospital in Norrköping and at Linköping University Hospital, both in the county of Östergötland. The multi-society *Clinical Practice Guidelines* of 2019, for the perioperative care of patients undergoing bariatric procedures, report on the utility of PRM to reduce postoperative pain, citing *Paper I*, lending further support to its clinical implication internationally.[190] The 2018 PROSPECT review also recommended evacuation of residual intraabdominal gas to reduce postoperative pain after laparoscopic cholecystectomy.[69]

Papers III and IV

Papers III and *IV* established benchmarks based on nationwide, real-world data from validated quality registries. *Paper III* defined more ambitious benchmarks than those of a previous study using a different methodology. Considering average international performance, the new reference values seem more relevant. *Paper IV* extended the approach to elective laparoscopic cholecystectomy, an area in which no standardized benchmarks had previously been developed.

Clinical implication

Surgical facilities performing laparoscopic Roux-en-Y gastric bypass, laparoscopic sleeve gastrectomy or elective laparoscopic cholecystectomy, in Sweden and internationally, may assess their performance and compare it with the benchmarks established in this thesis. Major performance gaps should drive local quality-improvement analyses and initiatives. The risk-adjusted benchmarks for diabetes in the LSG cohort and ASA ≥III in the ELC cohort provide a framework for more nuanced internal benchmarking that does not penalize facilities for accepting higher-risk patients.

Overall conclusion

Perfection in surgical care may not be fully attainable, but its pursuit remains essential. This thesis contributes to that pursuit by addressing both the details of clinical practice and the systems that shape outcomes. A simple pulmonary recruitment maneuver may improve postoperative recovery after laparoscopic upper abdominal surgery, while benchmarking can help surgical facilities identify performance gaps and guide quality improvement efforts. Together, these studies provide means to enhance upper abdominal laparoscopic surgery and, hopefully, improve outcomes for patients undergoing surgery for obesity and gallbladder disease.

FUTURE PERSPECTIVES

A pragmatic registry-based RCT (RRCT), analyzed by intention-to-treat, would be a potential path to facilitate evaluation of effectiveness, safety, and implementation of PRM under routine clinical conditions. The study could be integrated into SOReg and GallRiks on a voluntary basis, for surgical facilities agreeing to participate, with a case report form (CRF) including hemodynamic variables, adverse effects and PROMs. RRCTs have been performed in Sweden previously, such as the TASTE trial, evaluating treatment of myocardial infarction,[191] and specific RRCT guidelines have been developed.[192]

A new PRM trial should include a dedicated shoulder-pain intensity endpoint, apart from overall pain, as this best corresponds to the hypothesis of phrenic nerve irritation through residual gas beneath the diaphragm. Adverse outcomes of PRM should also be incorporated to evaluate safety and to determine whether certain patient categories are at increased risk.

The natural step following the benchmarking studies would be to close the loop. Collaborating with surgical facilities displaying lower-quartile performance (with inferior results also in current SOReg or GallRiks reports), a future multicenter quality-improvement study could evaluate whether individualized feedback of benchmark results, combined with root-cause analysis and targeted interventions, leads to measurable reductions in e.g. severe postoperative complications. Such a study would move benchmarking from a descriptive methodology toward an interventional tool for quality improvement. Additionally, successful modifications of perioperative routines would constitute performance drivers that may be transferable to other surgical facilities.

Moreover, future studies could explore organizational and perioperative characteristics of benchmark-setting facilities. Comparative qualitative or mixed-methods studies involving

benchmark-setting and lower-performing facilities may identify modifiable factors associated with superior outcomes, such as operative techniques, perioperative pathways, staffing models, case volume, or multidisciplinary infrastructure.

Finally, another possibility would be to prepare SOReg and GallRiks for the upcoming benchmark revision in a few years. Emerging technologies, including robotic surgery, evolving perioperative pathways, and changing patient populations, will necessitate periodic revision of benchmark values. Incorporation of PROMs such as postoperative pain and PONV into future benchmark panels would broaden assessment of surgical quality beyond traditional morbidity measures and better reflect patient-centered outcomes.

Furthermore, several process variables are already captured within the registries but are not mandatory, limiting their suitability for benchmarking due to missing data. By making selected process variables obligatory, such as time from consultation to surgery, prescribed medications, and use of evidence-based perioperative interventions, including PRM where appropriate, future benchmarking could establish aspirational targets with greater focus on quality-of-care processes.

APPENDIX

Patient questionnaire used in *Papers I and II*

Effekt av lungrekrytering på postoperativ smärta och illamående efter laparoskopisk bukkirurgi

IFYLLES X TIMMAR EFTER OPERATIONEN

SMÄRTA I VILA

Ringa in en siffra från 0 till 10 på skalan nedan!

0	1	2	3	4	5	6	7	8	9	10
Ingen smärta	Lätt		Måttlig		Medelsvår		Svår	Outhärdlig		Värsta tänkbara smärta

VAR GÖR DET ONT OCH HUR KÄNNS SMÄRTAN?

Om Du har ont, sätt ett kryss i den ruta som motsvarar smärtkaraktär och lokalisation!

VAR? / **HUR?**	HELA MAGEN	MAGENS ÖVRE DEL	AXEL	SÅR	ANNAT?
• molande					
• krampartad					
• tryckande					
• brännande					
• svidande					
• huggande					
• bultande					
• annat?					

	JA	NEJ
Kan Du röra dig i sängen?	☐	☐
Har Du kunnat gå upp ur sängen?	☐	☐
Har Du kunnat gå normalt?	☐	☐

ILLAMÅENDE I VILA

Ringa in en siffra från 0 till 10 på skalan nedan!

0	1	2	3	4	5	6	7	8	9	10
Inget illamående	Lätt		Måttligt		Medelsvårt		Svårt	Outhärdligt		Värsta tänkbara illamående

	JA	NEJ
Är Du illamående hela tiden?	☐	☐
...eller är Du illamående ibland?	☐	☐
Har du kräkts sedan op?	☐	☐
Har Du kunnat dricka något?	☐	☐
Har Du kunnat äta något?	☐	☐

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