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PhD thesis

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Annual volume and supervision in hernia repair, implications on risk of reoperation

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Annual volume and supervision in hernia repair, implications on risk of reoperation

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Publications included in the PhD thesis

Study I Christophersen C, Fonnes S, Andresen K, Rosenberg J. Lower recurrence rate after groin and primary ventral hernia repair performed by high-volume surgeons: a systematic review. Hernia 2022;26:29–37 [1].

Study II Christophersen C, Baker JJ, Fonnes S, Andresen K, Rosenberg J. Lower reoperation rates after open and laparoscopic groin hernia repair when performed by high-volume surgeons: a nationwide register-based study. Hernia 2021;25:1189–1197 [2].

Study III Christophersen C, Fonnes S, Baker JJ, Andresen K, Rosenberg J. Surgeon volume and risk of reoperation after laparoscopic primary ventral hernia repair: a nationwide register-based study. J Am Coll Surg 2021;233:346–356 [3].

Study IV Christophersen C, Fonnes S, Andresen K, Rosenberg J. Risk of reoperation for recurrence after elective primary groin and ventral hernia repair by supervised residents. JAMA Surg 2023;158:359–367 [4].

Introduction

Abdominal wall hernias

Both groin and ventral hernia repairs are common surgical procedures worldwide [5,6]. In Denmark there is around 9–10,000 groin hernia repairs and 4–5,000 ventral hernia repairs annually [7], making hernia repair one of the most frequent procedures in general surgery. A hernia consists of a hernial sac of peritoneum, which can contain intraabdominal viscera. The viscera protrudes through primary deficiencies in the musculoaponeurotic lamina of the abdominal wall through the hernial ring [8] (Figure 1). The term primary hernia refers to naturally occurring hernias while incisional hernias are a secondary deficiency in the musculoaponeurotic lamina in the area of a postoperative scar [9,10]. For the purpose of this thesis, primary hernias were divided into two categories: groin hernias which included primary inguinal and femoral hernias [11] and ventral hernias, including primary umbilical and epigastric hernias [9]. Hernia repairs can be performed with open or laparoscopic techniques, and the choice depends on the type and size of hernia, patient-specific factors, and the patient's as well as the surgeon's preferences and experience [12,13]. In Denmark, the use of laparoscopic approach for groin hernia repair has increased whilst the use of Lichtenstein technique has declined over the past decade [14].

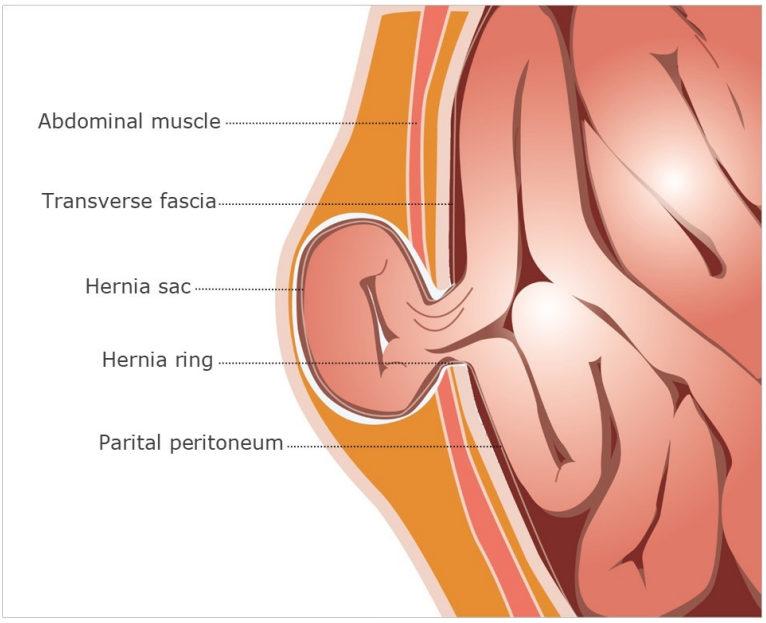

Figure 1. Anatomy of a hernia.

In the literature, long-term outcome measures after hernia repair vary between patient-reported quality of life measures, recurrence, or chronic pain [15]. Recurrence or reoperation for recurrence after hernia repair is a common quality measure in the literature and often used as a measure of success [12]. Recurrence occurs when the hernia defect reappears after the initial repair. In this thesis, reoperation was used as proxy for recurrence since it is the main reason for reoperation. Thus, in this thesis, the term reoperation refers to reoperation due to recurrence. Reoperation is a rather feasible outcome measure since it does not require clinician assessed recurrence and can be assessed via medical patient records, databases, or regional or nationwide registries. Whereas assessment of clinical recurrence can be time consuming and costly especially in large studies. Thus, large register-based studies most often use reoperation as a proxy for clinical recurrence [12]. However, the reoperation rate underestimates the clinical recurrence rate in both groin and ventral hernia repair. The clinical recurrence rate after groin hernia repair is approximately 40% higher than the reoperation rate [16] while the reoperation rate underestimates the overall risk of recurrence by four- to fivefold after ventral hernia repair [17]. Recurrence presents a challenge since it can ultimately necessitate reoperation for several patients which is costly. As for any other surgical procedures, reoperations are not without risk for the patients and there are even higher re-recurrence rates [18]. A reoperation rate of 8% after primary inguinal hernia repairs has been reported in the Danish Inguinal Hernia Database [19]. While reoperation and clinical recurrence rate has been reported as high as 15% after primary umbilical and epigastric hernia repairs in the Danish Ventral Hernia Database [17]. There are several factors influencing the risk of recurrence or reoperation after both groin [12,20,21] and ventral [22–27] hernia repair and some selected factors are shown in Figure 2.

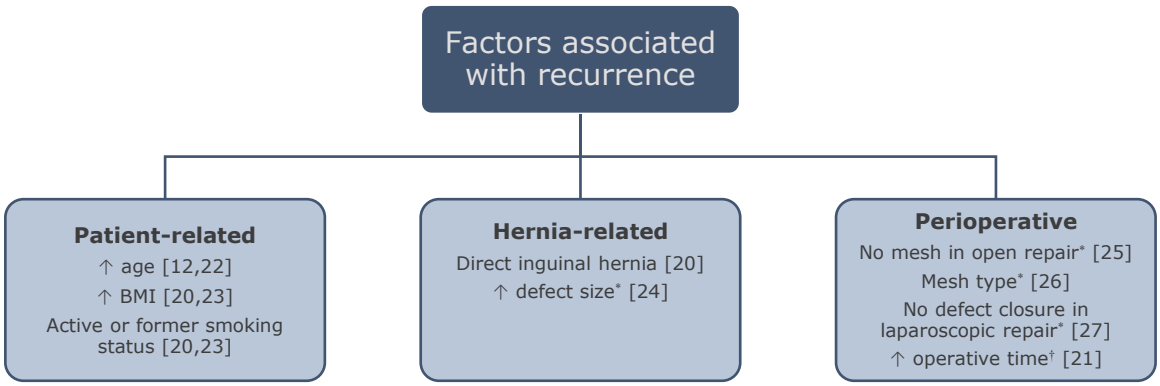

Figure 2. Selected factors associated with recurrence after primary groin and ventral hernia repair. BMI: Body Mass Index. *Ventral hernia. †Groin hernia.

Surgeons' experience also seem to affect the recurrence rates after hernia repair [28], and a previous register-based study showed a higher risk of recurrence after repairs performed by unsupervised trainees [29]. International guidelines for groin hernia repair state the importance of maintaining annual surgeon volume and experience in groin hernia repair [12]. However, the effects of surgical experience have only been investigated in few studies with low grade of evidence [12]. Thus, there is a need for further investigation of how annual surgeon volume affects recurrence rates after both groin and ventral hernia repair to ensure optimal outcomes for the numerous patients undergoing hernia repair each year. Furthermore, hernia repair is included in surgical training curricula worldwide, however, the number of hernia repairs performed by trainees vary [30]. It is important to evaluate how outcomes after hernia repair are affected when the repairs are performed by supervised residents, thus, finding a balance between surgical training and postoperative complications.

Acquiring surgical skills

Surgical residents train under the model of apprenticeship with increasing autonomy in the operating room [31], which entails a learning by doing or experiential learning approach. Since acquiring practical skills like those needed in surgery differ from acquiring theoretical knowledge [32], and acquiring surgical skills cannot be done without hands on experience. When learning new procedures residents must overcome their learning curve. Learning curves in hernia repair are assessed using different outcome measures such as reoperation or recurrence, operating time, or postoperative complications [33]. The learning curve is said to have been overcome when the rate of negative outcomes or operating time stabilizes at acceptable levels. Surgeon or resident specific factors might influence the number of procedures required to overcome the learning curve, such as stress or previous experience with other techniques. The learning curve varies, depending on the surgical approach and type of hernia, thus, laparoscopic TransAbdominal PrePeritioneal (TAPP) groin hernia repair requires 50–100 procedures [33] while Lichtenstein groin hernia repair requires around 40 procedures to overcome the learning curve [34]. For ventral hernia repair, guidelines published in 2020 suggested that the learning curve is around 20 and 30 procedures for laparoscopic and open ventral hernia repair, respectively [13]. However, the existing literature is limited on the learning curves for both laparoscopic and open ventral hernia repair, since most studies include both primary, recurrent, and incisional hernias. The surgical technique varies for primary and recurrent ventral, as well as incisional hernia repairs which alone includes many types of hernias

and thus varying techniques [35], leading to variations in the learning curves. In contrast to the volume-based learning curve analyses, competency-based evaluation is gaining popularity in the assessment of surgical proficiency in research [36]. Supervision by experienced surgeons plays an important role in both competency-based training and when mastering the learning curve [33].

Annual surgeon volume

Annual surgeon volume allows us to quantify how surgical experience is maintained. Annual surgeon volume has previously been used to assess the effect of surgeons' experience on patient-related outcomes [37]. High-volume surgeons have been associated with beneficial outcomes in several fields such as laparoscopic cholecystectomy [38], bariatric surgery [39], and laparoscopic colorectal surgery [40], showing the importance of maintaining surgical experience. Surgical experience can also be measured by the total number of procedures performed by the individual surgeon throughout their career. However, there is only limited evidence on this measure in the existing literature, and total surgical experience has only been reported in one study for hernia repair [41]. Additionally, total number of procedures throughout the individual surgeon's career is not a very precise measure of surgeons' experience since it does not necessarily take the length of their career into account and does not account for changes in caseload over time.

There are currently no guidelines on how many hernia procedures a surgeon must perform annually to be considered a specialist in hernia repair. The HerniaSurge Group published guidelines for groin hernia repair in 2018, underlining the importance of specialization in hernia repair, both for centers and surgeons, to improve postoperative outcomes for patients, however, this was based on low grade of evidence [12]. Centralization of hernia repairs in specialized centers could allow surgeons there to reach acceptable annual volumes and establish collaborations with other specialties if needed for rare or complicated cases.

Objectives

Overall, this thesis aimed to investigate how experience, measured as annual surgeon volume, and supervision affected the recurrence-related reoperation rate after both primary groin and primary ventral hernia repair. The objectives of each study were:

I. To systematically explore the effect of annual surgeon volume on recurrence or reoperation in groin, primary umbilical, and epigastric hernia repair, previously reported in the literature.

II. To investigate the effect of annual surgeon volume on risk of reoperation after primary groin hernia repair in Denmark.

III. To assess the effect of annual surgeon volume on the risk of reoperation after primary umbilical and epigastric hernia repair in Denmark.

IV. To evaluate how the risk of reoperation was affected after primary groin, umbilical, and epigastric hernia repairs, when the repair was carried out by supervised residents compared with specialists.

Methodological considerations

Ethical considerations

As medical researchers, we must adhere to the Helsinki Declaration, protecting the health, well-being, rights and interests of the individual, their privacy, and confidentiality [42]. Furthermore, we must adhere to national legislations and regulations, which is also stated in the Helsinki Declaration. According to Danish legislation, no ethical approval or written informed consent were needed for the systematic review and register-based studies included in this thesis. There are, however, still ethical aspects to consider.

Systematic reviews are considered the highest level of evidence [43]. Increasing access to research through the internet, and not exclusively in journals, has made published papers worldwide more accessible, leading to an increasing number of published systematic reviews [44]. Systematic reviews are frequently cited, and over the past four decades systematic reviews have played an increasing influential role in practice, policies, guidelines, and future research [45]. There is also the risk of including studies with ethical considerations of insufficient or low quality in systematic reviews [46]. This gives rise to ethical considerations to reduce spin, bias, misinterpretations in systematic reviews [47,48], and to ensure appropriate conduct of systematic reviews. Therefore, it is important to systematically consider the risk of bias in included studies and to report systematic reviews transparently. Transparency is increased by predefining a protocol which should be published in databases like the International prospective register of systematic reviews (PROSPERO) [49] or OSF [50]. Furthermore, protocol registration in PROSPERO, or similar databases, reduces duplicate work in research [51].

There are also ethical considerations when conducting observational register-based research. Register-based studies allow investigation of exposures and outcomes without subjecting patients to interventions, in contrast to randomized controlled trials (RCTs). The

register-based studies in this thesis assessed the effect of annual surgeon volume on the risk of reoperation. It would arguably have been unethical to randomize patients to surgeons based on annual volume, since we found increased recurrence and reoperation rates after hernia repairs by low-volume surgeons in the existing literature [1]. In Denmark, approval from the Danish Data Protection Agency [52] is required, ensuring protection of patients' data and privacy, when using Danish clinical quality registers. In accordance with Danish legislation, informed consent or ethical approval is not required to conduct register-based studies since the patients are not at any health risks, will not be contacted, or involved in the research projects [53], and data are only available for research and statistical analyses. Although ethical approval is not required, it is still mandatory to protect patients' privacy and anonymity [54], thus, data are pseudo anonymized and stored on safe servers. Lastly, when presenting data from register-based studies an ethical consideration to consider is how microdata is handled. Microdata, as defined by Statistics Denmark, are cells in tables with <3 observations since these are personally identifiable [55]. The register-based studies of this thesis included surgeons, and it was necessary to handle some of this data as microdata to ensure that no data were personally attributable.

Methodology of a systematic review

Systematic reviews systematically collects, evaluates, analyzes, and synthesizes empirical evidence from previously published research literature, based on predefined inclusion criteria to answer a specific research question [56]. Thus, providing a balanced summary of the current evidence and help in clinical decision-making since it is the highest level of evidence [43]. Systematic reviews can help when embarking on a new research question [56], allowing researchers to identify current studies and find gaps in the existing literature where there are implications for further research.

The systematic review in this thesis [1] was reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses statement (PRISMA) from 2009 [57]. Shortly after our systematic review was published, the updated PRISMA 2020 statement was published [58]. PRISMA 2020 is an elaborated version of the 2009 statement, but the key elements are the same. There are some noteworthy changes from PRISMA 2009 to 2020 such as reporting of the full search strategy for all databases searched; reporting of synthesis of results divided into six sub-items; assessment of certainty which is a new item introduced in the 2020 PRISMA statement; citing studies that seem to meet inclusion criteria but were excluded, with an explanation of exclusion; and reporting of funding of included studies. The use of reporting

guidelines helps ensure clear, accurate, and transparent reporting of the methods and results in medical research, which again increases the reproducibility of the individual study [59].
The research question was designed using the "PICO" framework, which includes a definition of the Population, Intervention, Comparisons, and Outcomes of interest in the review [60]. Furthermore, we defined what type of studies (S) were eligible for inclusion in our research question. A publicly accessible protocol was registered in PROSPERO (registration number: CRD42020176140) [61]. The search strategy was developed in cooperation with a professional information specialist from the Copenhagen University Library, optimizing the search string so it included as many relevant records as possible whilst limiting the number of irrelevant records [62]. We searched PubMed, Embase, and Cochrane CENTRAL [63], thus, retrieving records only available in one database [64], ensuring a wider inclusion of records. Furthermore, we conducted a search of the included records' references since browsing the references of included records is an effective way to identify relevant records that were not identified by the search strategy [65]. The title and abstracts of records yielded by the search of the three databases were screened in parallel, independently by two authors and conflicts were resolved within the author group. The initial title abstract screening was then followed by a full-text screening, which was also performed in parallel. In parallel screening assured that fewer records were missed in the screening process compared with single screening [66]. Risk of bias in the included observational studies was assessed with the Newcastle-Ottawa Scale (NOS) for assessing quality of nonrandomized studies in meta-analyses [67], and risk of bias in the included RCT was assessed using the Cochrane Risk of Bias tool from 2011 [68]. We initially sought to compare the recurrence rates after hernia repairs performed by low- compared with high-volume surgeons. But, due to the varying definitions and categorizations of annual surgeon volume in the included studies, we implemented a medium volume category, resulting in three overlapping volume categories: low- (≤25 cases/year), medium- (11–50 cases/year), and high-volume (>50 cases/year).

As stated in the protocol [61], meta-analyses were planned if possible which was evaluated by assessing the heterogeneity across the included studies. It is important to distinguishing between clinical, methodological, and statistical heterogeneity [69], a distinction we should have made in our systematic review. Clinical heterogeneity refers to the variability in participants, interventions, and outcomes in the study. Methodological heterogeneity refers to the variability in the study design, outcome measures, and risk of bias. While statistical heterogeneity arises from variability in the intervention effects of the included studies [69]. The statistical heterogeneity can be quantified using the I^2 statistic, ranging from 0–100%. I^2 between 0–40%

means that the statistical heterogeneity might not be important; 30–60% indicates moderate statistical heterogeneity; 50–90% indicates substantial statistical heterogeneity; and 75–100% indicates considerable statistical heterogeneity [69]. We tried to perform a meta-analysis using the OpenMeta[Analyst] software [70], however, this resulted in considerable statistical heterogeneity (I^2>86%) which should have been reported in the systematic review. Due to the considerable statistical heterogeneity, we initially decided against conducting any meta-analyses. However, a study has since then pointed out that in meta-analyses of prevalence high statistical heterogeneity is frequent but not a sign of important variability across the included studies [71]. Because variations in prevalence arises from clinical and methodological variability such as grouping or subgrouping of patients, follow-up time, and outcome measures. It is to be expected that inclusion of cohort studies with wider variation in methodology will lead to a higher statistical heterogeneity in comparison to inclusion solely of RCTs with highly selected study populations. In prevalence meta-analyses, instead of evaluating the statistical heterogeneity with the I^2 statistic, it would be more appropriate to assess the clinical and methodological variations across included studies by estimating the prediction intervals [71]. All in all, it would have been more correct had we assessed the clinical and methodological variations in the included cohort studies, evaluating eligibility for meta-analyses for prevalence with a more lenient interpretation of I^2. This should then had been followed by sensitivity analyses to explore heterogeneity, which should be planned in the protocol. After publication of the review, we further explored the possibilities of performing meta-analysis, but for methodological reasons we had to abstain from that (see Strengths and limitations of Study I).

Methodology of register-based studies

Observational studies such as studies including data from the Danish Hernia Database allow us to compare exposures and outcomes in many patients without allocating patients to new treatments [72]. Observational register-based studies allow for longer follow-up times. Furthermore, register-based studies allow us to include patients that are usually excluded from RCTs such as elderly patients and patients with comorbidities [73], leading to an increased external validity [72–74].

The register-based studies included in this thesis [2–4] were reported using the REporting of studies Conducted using Observational Routine-Collected health Data (RECORD) statement [75]. The RECORD statement is an extension of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [76]. The STROBE statement was

designed to apply to observational studies, and the RECORD statement adds items when reporting results based on routinely collected health data [75]. Furthermore, the RECORD statement includes items on reporting of linkage between databases, which applied to all three register-based studies included in this thesis. Again, the use of reporting guidelines ensures clear and transparent reporting of findings and increases the reproducibility of results in medical research [59]. In this thesis, we included adults undergoing repair for primary inguinal, femoral, umbilical, or epigastric hernias with open or laparoscopic approach. The outcome of interest was reoperation due to recurrence.

Denmark has a long tradition of nationwide registers of routinely collected data accessible for register-based research [77]. This includes administrative databases such as the Danish National Patient Registry [78] and the National Civil Registration System [79], as well as clinical quality databases such as the Danish Hernia Database [80,81]. Clinical quality databases collect clinical data for clinical quality control. These databases are regulated by the government, funded publicly [77], and entry in the clinical quality databases is mandatory for both public and private health care providers [54], resulting in high registration rates in the Danish clinical quality databases. The Danish Hernia Database was established to improve postoperative outcomes after hernia surgery in Denmark [80,81]. The Danish Hernia Database consists of two separate branches: the Danish Inguinal Hernia Database, which was established in 1998 [80] and the Danish Ventral Hernia Database, which was established in 2007 [81]. In 2021, the national registration rates were 94% and 89% in the Danish Inguinal and Ventral Hernia Database, respectively [7]. Data were extracted through the Danish Clinical Quality Program–National Clinical Registries (RKKP) [82] and linked with data from the Danish National Patient Registry [78] and the Danish Civil Registration System [79] via patients' unique personal identification number. Patients were followed via the Danish Hernia Databases. With reoperation as outcome measure, the follow-up was close to 100% since reoperations not registered by surgeons in the Danish Hernia Databases are registered in the Danish National Patient Registry and, thus, included in the extracted data. Data from the Danish Civil Registration System provides information on patients' who died or emigrated during the study period, adding to the follow-up rate. The Danish Inguinal and Ventral Hernia Database includes many variables [83] describing patient-, hernia-, perioperative-, and surgeon-specific factors and an overview of selected variables is presented in Table 1. The validity of the variables in the Danish Ventral Hernia Database has a high agreement with hospital records, however, this is based on a study from 2013 [84]. Since then, more variables have been implemented in the Danish Ventral Hernia Database that have not been validated (Table 1). The variables in the Danish Inguinal Hernia

Database have not been validated. However, since the Ventral Hernia Database has a high agreement between the database and hospital records it could be assumed that the Inguinal Hernia Database correspondingly has a high agreement since the nature of the variables is similar and there is an overlap between the surgeons who register hernia repairs in both arms of the database. Furthermore, data in the Inguinal and Ventral Hernia Database are validated against the National Patient Registry [80,81]. Data on surgeons were extracted from the Danish Patient Safety Authority's Online Register [85] via surgeons' unique authorization IDs that was also used to link surgeon data with data from the Danish Hernia Databases. The Danish Patient Safety Authority's Online Register is a publicly available register [85] and contains data on all authorized health professionals in Denmark, including physicians. We used data on operating surgeons' date of birth, date of authorization (i.e., graduation), field of specialization, and date of acquired specialization.

		Danish Hernia Database		
	Variable	**Inguinal**	**Ventral**	**Comment**
Patient-specific	Age	✓	✓	
	Sex	✓	✓	
	BMI	×	✓	Since 2016
	Smoking status	×	✓	Since 2016
Hernia-specific	Type of hernia	✓	✓	
	Hernia defect size	✓	✓	Inguinal: EHS, Ventral: cm
Peri-operative	Date of operation	✓	✓	
	Primary or recurrent repair	✓	✓	
	Surgical approach	✓	✓	
	Type of mesh	✓	✓	
	Anatomical mesh placement	×	✓	
	Anesthesia	✓	×	
Surgeon-specific	Supervision	✓	✓	Fully implemented in 2016
	Authorization ID	✓	✓	Fully implemented in 2016

Table 1. Overview of selected variables in the Danish Inguinal- and Ventral Hernia Database. BMI: Body Mass Index. EHS: European Hernia Society classification [11]. ✓: Variable available in the databases. ×: Variable not available in the databases.

Statistical considerations

This section describes the statistical considerations of register-based studies since the statistical considerations of meta-analyses are described under the Methodology of a systematic review.

The distribution of continuous data can be assessed visually with histograms and Quantile-Quantile (Q-Q) plots, which was used in this thesis. A Q-Q plot is a scatter plot, plotting two sets of quantiles, quantiles of observed data on the y-axis and quantiles of expected data on the x-axis. Normally distributed data will align with the 45° diagonal reference line [86]. If data are not normally distributed normality can sometimes be achieved by transforming data, and

a logarithmic transformation is frequently used [86], which makes differences between observations smaller. For the studies included in this thesis, normal distribution was not required since the main analyses were Cox Proportional Hazard Analyses [87].

For descriptive statistics of categorical data, the Chi-square of Independence test was used in this thesis. This is a pairwise comparison test of non-parametric data which assesses the independence between two or more variables. An underlying assumption of the Chi-square test is that data are distributed in categorical variables with independent groups where each observation is only present in one category [88]. If the expected number of observations were <5 Fischer's Exact test was used instead. For descriptive statistics of non-parametric continuous data, we used the Kruskal Wallis test. This is an omnibus test for median difference between groups. The Kruskal Wallis test was followed by Dunn's test which is a multiple pairwise comparison. Dunn's test is adjusted for multiple comparisons with the Bonferroni correction, reducing risk of statistical type I error by reducing the *p*-value required to accept statistical significance [89]. However, this comes with an increased risk of a statistical type II error [90]. A statistical type I error is the rejection of a true null hypothesis, which arises from the chosen significance level. While a type II error is the failure to reject a true null hypothesis, which correlates to the statistical power of the test in question [91].

The exposure investigated in study II and III [2,3] was annual surgeon volume, calculated as a dynamic variable. We defined annual surgeon volume as the number of procedures performed by the individual surgeon 12 months prior to the index hernia repair, separately for each operative approach. This allowed surgeons to change volume categories throughout the study periods, in contrast to simply using the calendar year of the index hernia repair to estimate the annual surgeon volume. By calculating annual surgeon volume as a dynamic variable, we obtained a more accurate estimate for the individual surgeon's annual volume, thus, limiting misclassification of surgeons that would otherwise have arisen from the retrospective design of these studies.

Cox Proportional Hazard Analyses, or Cox regression, were used for the main analyses in study II, III, and IV [2–4]. The Cox regression is a survival analysis, and it is adjusted for the individual patient's follow-up time. Thus, the Cox regression takes the time from intervention, in this thesis hernia repair, to event (reoperation), death, emigration, loss to follow-up, or end of the study period into account by censoring patients from the analysis. The output is presented as a Hazard Ratio (HR) with a corresponding 95% confidence interval (CI) for each category or group investigated. The HR is the probability or risk of an event at any given time, and a HR <1 indicates a reduced risk while a HR >1 indicates an increased risk of the event occurring

compared with a reference group [87]. The Cox regression relies on the assumption that the hazard functions over time are proportional. This proportionality can be assessed with log-log survival plots, plotting the logarithm of the cumulative hazard function and the logarithm of time in each group, if the lines are parallel this proportionality assumption is fulfilled [92]. The Cox regression is a multivariable analysis, making it possible to adjust for categorical and continuous covariates. The statistical power of survival analyses is associated with the number of events, rather than the number of participants, and inclusion of too many covariates in the analyses will lead to a loss of power to identify associations in the analyses. To minimize this loss of power, it has been recommended that at least 10 observed events should be present per included covariate [93]. There are different methods for choosing covariates to include such as backward stepwise elimination or a theory-based approach. The backward stepwise elimination consists of several analyses, where one covariate is eliminated at each step, using a predefined *p*-value cut-point [94], we used $p > 0.2$. This method has been critiqued since the final model is solely based on statistical significance. In the theory-based approach covariates are chosen based on the specific research question and clinical relevance [92]. Thus, choosing covariates known to affect the outcome of interest.

Kaplan-Meier plots are illustrative plots of time to event, which is often time to death, in this thesis it was time to reoperation. This results in a predicted survival curve, or in this thesis curves of cumulative reoperation rates. These survival curves are typically presented for more than one group, with the cumulative probability of the given event over time, related to the number of patients in a given time interval. In Kaplan-Meier plots, participants are followed over time, censoring participants at time of death or emigration. Kaplan-Meier plots are a univariate approach, in contrast to Cox Proportional Hazard Models. The log-rank test can be used to compare the full curves of each group in the Kaplan-Meier plot and provides a significance level. The underlying assumptions of Kaplan-Meier plots are that censored and uncensored participants have the same probability of the event occurring, and that the probability of the event occurring is the same regardless of when participants enter the study [95].

Study presentation

Study I: Lower recurrence rate after groin and primary ventral hernia repair performed by high-volume surgeons: a systematic review [1]

Background and aim

International guidelines for groin hernia repair have been published, stating the importance of maintaining annual surgeon volume in groin hernia repair. However, this has only been investigated in few studies [12] and it was necessary to assess how annual surgeon volume has been reported in the existing literature as the first step of this thesis.

This study aimed to investigate how annual surgeon volume and total surgical experience affected outcomes after groin, as well as primary umbilical and epigastric hernia repair.

Methods

We searched three databases. We included studies with adult patients operated for groin hernia with Lichtenstein, laparoscopic TAPP, or Totally ExtraPeritoneal (TEP) techniques, or for primary umbilical or epigastric hernias with open or laparoscopic approach. The intervention of interest was high annual surgeon volume or total surgical experience, while the comparator was low annual surgeon volume or total surgical experience. The outcome of interest was recurrence. Studies were excluded if they were systematic reviews or case series or reports with <5 surgeons. Only studies in English and Scandinavian languages were considered for inclusion. The primary outcome was recurrence rate after hernia repair according to annual surgeon volume. We pooled surgeons into overlapping high-, medium-, and low-volume categories. No meta-analyses were conducted.

Results

Of 1,980 records identified, 10 reports based on seven studies were included, covering 476,448 unique patients who underwent groin hernia repair (seven studies), and 78,267 patients (one study), who underwent primary umbilical or epigastric hernia repair. The included observational studies had an overall low to medium risk of bias, according to the Newcastle-Ottawa Scale. The included RCT [41] was assessed to have a high risk of bias. Recurrence was diversely defined as reoperation, patient reported recurrence, or clinician assessed recurrence in the included studies. Recurrence or reoperation rate after groin hernia repair based on annual surgeon volume was

pooled separately for five studies that showed a tendency of increased recurrence or reoperation rate among low-volume surgeons (Figure 3).

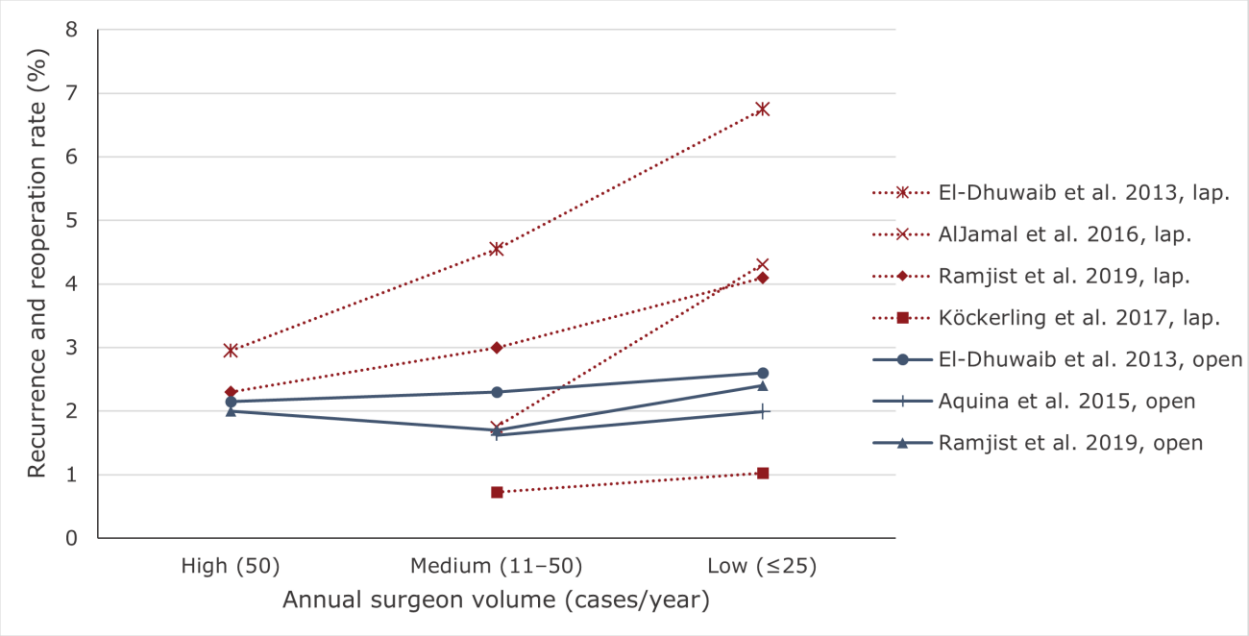

Figure 3. Pooled recurrence or reoperation rate after laparoscopic (red punctuated line) and open (blue line) groin hernia repair based on annual surgeon volume. Lap.: laparoscopic. Adapted from study I [1].

The study on primary umbilical and epigastric hernia repair showed that high annual surgeon volume was associated with a lower reoperation rate, while lower volume surgeons were associated with higher reoperation rates [96].

Conclusion

This systematic review showed a tendency of higher recurrence or reoperation rates after groin hernia repairs performed by low-volume surgeons, and available data suggested that surgeons should perform at least 25 cases/year. Only one study reported on reoperation after umbilical and ventral hernia repair based on annual surgeon volume.

Strengths and limitations

A MeaSurement Tool to Assess systematic Reviews version 2 (AMSTAR 2) can be used to critically asses systematic reviews [97], and it includes 16 items, of which four items concern meta-analysis (item 11, 12, 14, and 15) which were not relevant for this systematic review since no meta-analyses were conducted. Overall, this systematic review was appraised to have moderate quality, meaning that the systematic review did not have any critical flaws but more than one non-critical weakness. A strength to this systematic review was that a protocol was uploaded to PROSPERO [98] before data extraction began (AMSTAR 2, item 2), thus

minimizing the risk of reporting bias. The search strategy was developed in cooperation with an information specialist, we searched three databases, and the exact search strategy was stated in the systematic review. The search was conducted within one year of the completion and publication of the systematic review, ensuring that the systematic review reflected the current published literature. Furthermore, we conducted a search of all included records' references, identifying records in obscure locations [65]. To further widen the search strategy, we could have searched trial and study registries or grey literature (AMSTAR 2, item 4). In addition, we could have performed a forward citation search by screening records citing the records included in this systematic review to widen the search strategy [99]. The data extraction was performed by one author, using a predefined Excel sheet, however, according to AMSTAR 2 the data extraction should be performed independently by two reviewers (AMSTAR 2, item 6). However, the data extraction was performed twice by the same author, ensuring accuracy of the extracted data. Funding of the included studies was not extracted (AMSTAR 2, item 10) since this item was not included in the PRISMA statement before the updated 2020 statement [58] which was published shortly after our systematic review [1]. Funding is important to assess since the sources of funding might affect the reporting of the results in studies eligible for inclusion in systematic reviews. Studies sponsored by pharmaceutical, medical devices, or other forms of industry often have more favorable efficacy results compared with non-industry funded studies. Differences in efficacy results due to sources of funding are rarely detected in risk of bias assessments. Furthermore, industry sponsored studies often have less agreement between the results and conclusions, known as Industry Sponsorship Bias [100]. The exposures in our systematic review were annual surgeon volume and total surgical experience which was most likely not affected by funding. However, materials used and outcome assessment in the included studies could be affected by funding source.

The published systematic review does not contain any meta-analyses due to considerable statistical heterogeneity. This was assessed for the three studies [101–103] that allowed us to group patients by annual surgeon volume, using 25 cases/year as cut-off, since this was the most frequently used volume cut-off in all the included studies. Upon revisiting the included studies of the systematic review after its publication, we tried to assess if it would be possible to conduct any meta-analyses assessing prevalence of recurrence for low-, medium-, and high-volume surgeons, respectively after groin hernia repair. However, we deemed that the methodological heterogeneity of the included studies was too high due to variations in follow-up times from 12–72 months [102,104]. Since recurrence rate also depends on follow-up time [105], results of a meta-analysis of studies with varying follow-up times could be misleading since studies

with a longer follow-up time most likely have a higher recurrence rate. There was also a wide range of how the outcome recurrence was reported in the included studies ranging from patient reported symptoms of recurrence to reoperation for recurrence. Since clinical recurrence is approximately 40% higher than reoperation rate for groin hernias [16], we deemed that these outcome measures were not comparable across the included studies. Furthermore, the varying reporting of annual surgeon volume categories across the included studies made it difficult to compare volume categories. This methodological heterogeneity could be explored with sensitivity analyses, however, we deemed that it would not be meaningful here since our systematic review included few studies, and since we decided against conducting meta-analyses.

Study II: Lower reoperation rates after open and laparoscopic groin hernia repair when performed by high-volume surgeons: a nationwide register-based study [2]

Background and aim

We found that high annual surgeon volume was associated with lower recurrence rates after groin hernia repair through our systematic review [1]. However, this has not previously been investigated in a nationwide cohort including both private and public health care providers.

The aim of this study was to investigate the effects of annual surgeon volume on reoperation rates for recurrence after primary groin hernia repair in a nationwide setting.

Methods

This was a nationwide register-based study based on prospectively collected data on groin hernia repairs from the Danish Inguinal Hernia Database [80] linked with data on surgeons from the Danish Patient Safety Authority's Online Register [85] via surgeons' unique authorization ID. The study period ran from January 2011 to January 2020. However, authorization ID, used to calculate annual surgeon volume did not become a required entry in the Inguinal Hernia Database until 2016. Patients were followed until reoperation, death, or the end of the study period. Reoperation was defined as an operation due to a hernia recurrence for a groin hernia on the same side, following the index operation. Data were restructured, allowing us to consider groin hernia repairs for inclusion. Eligible groin hernia repairs were elective and emergency primary inguinal or femoral hernia repairs performed in adult patients operated with Lichtenstein or a laparoscopic TAPP approach. Since Lichtenstein technique is the most common approach for open inguinal hernia repair, and TAPP is the most common approach for laparoscopic groin

hernia repair in our study population [106]. We excluded patients who had emigrated during the study period or had residence outside of Denmark. Eligibility criteria for surgeons were a valid entry of authorization ID that had been registered ≤2 times in the study period. The primary outcome was reoperation rate due to recurrence divided by annual surgeon volume categorized into ≤10, 11–25, 26–50, 50–100, and >100 cases/year. Risks of reoperation for recurrence based on annual surgeon volume were assessed with Cox Proportional Hazard Analyses for Lichtenstein and TAPP repair, respectively.

Results

This study included 9,898 groin hernia repairs in the Lichtenstein cohort performed by 546 surgeons, and 15,362 groin hernia repairs in the TAPP cohort performed by 331 surgeons. In the Lichtenstein and laparoscopic TAPP cohort, the crude reoperation rates were 2.6% and 2.2%, respectively. The median (IQR) time to follow-up was 24 (13–34) months in the Lichtenstein cohort and 22 (11–33) months in the TAPP cohort. In both the Lichtenstein and TAPP cohort, we found significantly increased risks of reoperation for lower volume surgeons compared with high-volume surgeons (see Table 2).

Annual surgeon volume (cases/year)	Hazard ratio	95% confidence interval
Lichtenstein repair*		
≤10	4.02	1.27–12.75
11–25	3.64	1.15–11.58
26–50	3.93	1.22–12.64
51–100	4.30	1.27–14.54
>100	1	
TAPP repair†		
≤10	1.89	1.29–2.77
11–25	2.08	1.43–3.01
26–50	1.80	1.25–2.59
51–100	1.58	1.11–2.24
>100	1	

Table 2. Adjusted risk of reoperation after Lichtenstein and TransAbdominal PrePeritoneal (TAPP) laparoscopic primary groin hernia repair. *Cox regression adjusted for patients' age, sex, type of hernia, defect size according to the European Hernia Society classification [11], and method of anaesthesia. †Cox regression adjusted for patients' age, sex, type of hernia, and defect size. Adapted from study II [2].

Conclusion

We found a significantly higher risk of reoperation due to recurrence after primary groin hernia repairs performed by low- and medium-volume surgeons compared with high-volume surgeons after both Lichtenstein and TAPP primary groin hernia repair.

Strengths and limitations

This study is strengthened by the inclusion of groin hernia repairs from the Danish Inguinal Hernia Database, which is nationwide and includes patients operated in both the public and private health sector. Between 2016 and 2020 the national registration rate in the Danish Inguinal Hernia Database was approximately 90% [107–110], thus, reflecting a fully representative cohort. The Danish Inguinal Hernia Database contains prospectively collected data, and there are limitations to consider when using prospective databases for a retrospective study design. The data collected in clinical databases are not collected for research of specific outcomes, therefore the data availability is limited [111]. E.g., we used reoperation as proxy for the recurrence rate as the primary outcome, and since the clinical recurrence rate is approximately 40% higher than the reoperation rate [16] this could lead to an underestimation of the actual recurrence rate. There may also be unrecognized differences in baseline characteristics, or confounders [111], such as smoking and Body Mass Index (BMI) that seem to be associated with an increased risk of recurrence after inguinal hernia repair [20]. Due to the retrospective design of this study, it was not possible to adjust for these factors since they are not available in the Danish Inguinal Hernia Database. There are also several strengths to a retrospective study design. It enables researchers to include many patients in one study. Retrospective studies like this study comes with a risk of loss to follow up. However, this study had nearly 100% follow-up rate since the Danish Inguinal Hernia Database also draws data from the Danish National Patient Registry [78], retrieving groin hernia repairs and reoperations that were not entered manually in the database. Furthermore, the database also includes data from the Danish Civil Registration System [79], allowing us to identify patients who emigrated or had residence outside of Denmark.

We included groin hernia repairs performed from November 2011 until January 2020. However, authorization ID did not become a required entry in the Danish Inguinal Hernia Database until 2016, resulting in an effective study period from 2016 and onward. In this study, we excluded surgeons if their authorization IDs only figured ≤2 times in the database since we deemed it unlikely that one surgeon would perform ≤2 hernia repairs in the whole study period, and we assumed that these entries were incorrect. Since then, we realized this was unnecessary because we cannot know where included surgeons were in their career or training when they entered our study period. If surgeons entered late in our study period, they might have performed less than two groin hernia repairs, resulting in less than two registrations of their authorization ID. We calculated annual surgeon volume as a dynamic variable. However, this was not possible during the first year that the individual surgeons figured in the database, and annual surgeon

volume during the first year was defined as the number of procedures during the first year. To see if including annual surgeon volume calculated for the calendar year (i.e., not dynamic) would change the outcome, we conducted sensitivity analyses only including repairs where it was possible to calculate annual surgeon volume as a dynamic variable. The increased risk of reoperation after groin hernia repair based on annual surgeon volume was significant in the 26–50 and 51–100 volume categories of the Lichtenstein cohort and the 26–50 volume categories in the laparoscopic TAPP cohort compared with high-volume surgeons [2]. However, fewer observations were included in the sensitivity analyses, leading to an increased risk of a statistical type II error in the sensitivity analyses. The outcome of interest was reoperation after primary groin hernia due to recurrence, and we assured that this outcome was not present at inclusion by excluding recurrent groin hernias. Furthermore, we conducted a "look back" from the implementation of the Danish Inguinal Hernia Database, identifying groin hernia repairs preceded by a previous repair on the same side which were also excluded as recurrent groin hernias.

We did not use descriptive statistics to test for any differences in characteristics of groin hernia repairs across the volume categories, and we cannot deny differences in patient characteristics across the annual surgeon volume categories. However, relevant factors associated with recurrence were included and adjusted for in the Cox regressions and did therefore not affect the estimated risks of reoperation. We followed the patients until death, reoperation, or the end of the study period whilst excluding patients who had emigrated during the study period. However, these could have been included and censored in the Cox regression, at the time of emigration instead of excluding them. This only accounts for approximately 150 groin hernia repairs which would not impact the results of the study. Since the Cox regression allows to censor cases at the date of emigration, it would have been just as correct to include these groin hernia repairs in the study and have them censored in the Cox regressions, allowing the emigrated patients to contribute with time-at-risk to the main analyses. In this study, we conducted several Cox regressions since there were five volume categories in the two cohorts, this multiple testing comes with a risk of type I errors. This risk could have been mitigated by adjusting for multiple testing with corrections such as the Bonferroni correction which reduces the *p*-value for statistical significance. However, the Bonferroni correction is considered stringent by many, and is not without risk of type II errors due to the more stringent significance level which in turn could lead to a false acceptance of the null hypothesis. Furthermore, the interpretation of the findings will depend on the number of tests performed with the Bonferroni correction [90]. Because of this, we decided against adjusting for multiple testing.

Study III: Surgeon volume and risk of reoperation after laparoscopic primary ventral hernia repair: a nationwide register-based study [3]

Background and aim

Only one previously published study has investigated the effect of annual surgeon volume on reoperation rate after primary ventral hernia repair [96], however, their population was selected based on diagnostic codes which did not fully distinguish between primary and recurrent ventral hernias.

The aim of this study was to investigate the effect of annual surgeon volume on the reoperation rate for recurrence after primary umbilical and epigastric hernia repair in a nationwide setting.

Methods

We included nationwide prospectively collected data from the Danish Ventral Hernia Database [81] on ventral hernia repairs and data on surgeons were obtained from the Danish Patient Safety Authority's Online Register [85]. The study period went from January 2011 to January 2020. Patients were followed until death, reoperation, emigration, or the end of the study period. Reoperation was defined as a hernia registered as a reoperation or a subsequent ventral hernia repair. We included elective and emergency primary umbilical or epigastric hernia repairs in adult patients operated with open or laparoscopic approach. Patients were excluded based on operative specific characteristics, such as use of component separation, resorbable mesh types, and Physiomesh® since this mesh was withdrawn due to an increased risk of recurrence [112]. Surgeons were included if there was a registered valid authorization ID. The primary outcome was recurrence related reoperation rate based on annual surgeon volume. Annual surgeon volume was categorized into ≤9, 10–19, 20–29, and ≥30 cases/year [96]. The repairs were analyzed as three separate cohorts, depending on the surgical approach: open mesh, open non-mesh, and laparoscopic primary ventral hernia repair cohort. Cox Proportional Hazard Analyses were used to assess risks of reoperation due to recurrence after primary ventral hernia repair based on annual surgeon volume separately for the three cohorts.

Results

This cohort study included 4,138 patients in the open mesh cohort operated by 592 surgeons, 2,201 patients in the open non-mesh cohort operated by 514 surgeons, and 1,529 patients in the laparoscopic cohort operated by 209 surgeons. The crude reoperation rates in the open mesh, open non-mesh, and laparoscopic cohorts were 2.0%, 4.7%, and 2.4%, respectively. The median (IQR) time to follow-up was 19 (9–31) months in the open mesh cohort, 26 (13–35) months in the open non-mesh cohort, and 23 (13–33) months in the laparoscopic cohort. In the laparoscopic cohort, there was a significantly increased risk of reoperation (HR [95% CI]) after primary ventral repairs performed by surgeons with an annual volume of ≤9 (6.57 [1.63–26.46]), 10–19 (6.58 [1.53–28.22]), and 20–29 (13.59 [3.05–60.61]) compared with ≥30 cases/year. The risk of reoperation was adjusted for elective versus emergency repair, mesh placement, and type of tacks used. The cumulative risk of reoperation after laparoscopic primary ventral hernia repair is shown in Figure 4.

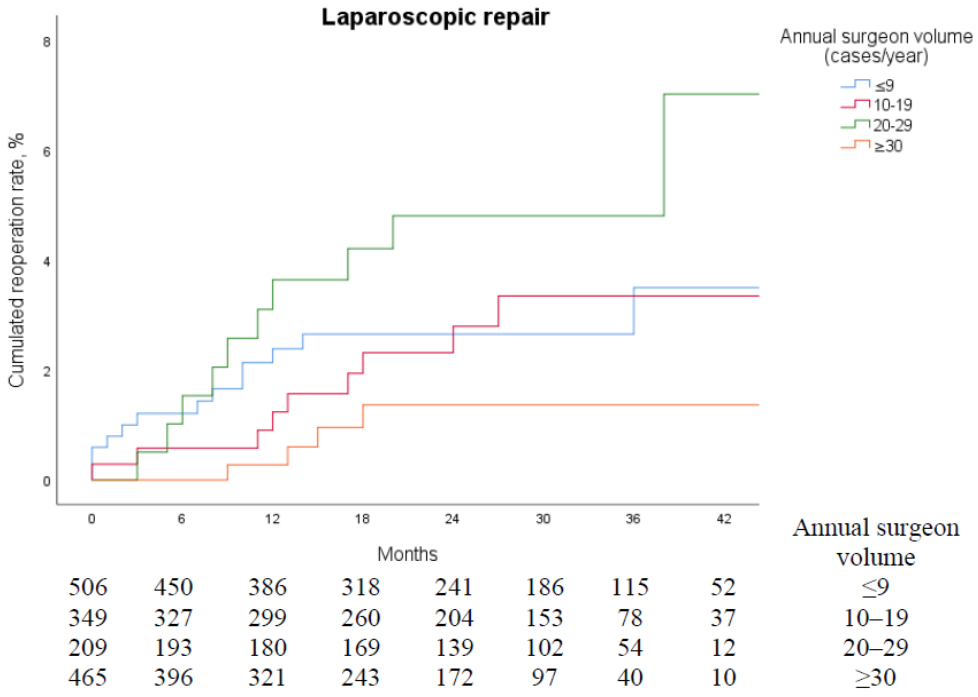

Figure 4. Kaplan-Meier plot depicting the cumulative reoperation rates along with the number at risk after laparoscopic repair of primary umbilical and epigastric hernias divided by annual surgeon volume ($p = 0.070$). Reproduced with permission from Wolters Kluwer [3].

Conclusion

This study showed an increased risk of recurrence related reoperation after laparoscopic repair of primary umbilical and epigastric hernia repairs performed by low- and medium-volume surgeons compared with high-volume surgeons.

Strengths and limitations

This study included data from the Danish Ventral Hernia Database which has nationwide coverage. The national registration rate between 2016 and 2020 was approximately 80% across the public and private health sector [107–110], resulting in an almost fully representative cohort. We included primary umbilical and epigastric hernias, whilst excluding incisional hernia repairs which strengthened the results of this study since primary and incisional hernia vary in surgical management, as well as postoperative outcomes such as recurrence-related reoperation rate. Thus, pooling primary and incisional ventral hernias in the same analyses can lead to skewed results [35,113]. The previously published guidelines regarding management of ventral hernias have included both primary and incisional ventral hernia repairs [114,115]. A more recent guideline for the management of primary umbilical and epigastric hernia was published in 2020 [13]. However, the evidence of this guideline is still limited by the available literature since many studies are still pooling primary and incisional ventral hernia repairs. We also conducted a "look back" in the Danish Ventral Hernia Database to identify ventral hernia repairs followed by subsequent repairs which were defined as reoperations and thus, excluded. We followed patients until death, emigration, reoperation, or the end of the study period, and the follow-up rate was close to 100% since the Danish Ventral Hernia Database also draws data from the Danish National Patient Registry [78] and the Danish Civil Registration System [79]. In this study, we included patients who emigrated after their hernia repair by censoring them in the Cox regression at time of emigration, thus allowing the emigrated patients to contribute with time-at-risk to the analyses. The median time to follow-up in the laparoscopic, open mesh, and open non-mesh cohorts were 23, 19, and 26 months, respectively. A previous study showed that approximately 80% of recurrences after ventral hernia repair occurred during the first two years [116] and thus, we can assume that the majority of recurrences occurred during our follow-up period.

We included ventral hernia repairs performed from January 2011 until January 2020. However, authorization ID did not become a required entry in the Danish Ventral Hernia Database until 2016, leading to an effective study period from 2016–2020 where the majority of the included ventral hernia repairs were performed (98%). Between 2011 and 2016, there were

166 (2%) ventral hernia repairs. This gives rise to a possible misclassification of annual surgeon volume category for these repairs, since far from all repairs were registered with authorization ID used to calculate annual surgeon volume, between 2011 and 2016. It was not possible to see how surgeons were misclassified in the 2% of the ventral hernia repairs, and therefore not possible to see if this was a question of differential or non-differential misclassification bias. This risk of misclassification bias could have been avoided altogether by excluding the repairs performed before 2016. In contrast to study II [2], we included all surgeons with a valid authorization ID registered in the Patient Safety Authority's Online Register [85], belonging to a medical doctor, in this study. This was a safe and robust definition of valid authorization ID and incorrect entries of authorization IDs were highly unlikely, allowing us to include surgeons who had just begun to perform ventral hernia repairs.

The primary outcome was analyzed with Cox regressions. In the laparoscopic cohort there were 36 events, thus, we chose to limit the number of included covariates in this Cox regression to four, so there was approximately one covariate for every ten events in the Cox regression to limit the risk of overfitting the model [117]. The covariates included in the Cox regression for laparoscopic ventral hernia repair were annual surgeon volume, elective versus emergency repair, mesh placement, and type of tacks used. These covariates were chosen based on backwards stepwise elimination. Ideally, the Cox regression should also have been adjusted for patients' age and sex, BMI, smoking status, mesh overlap, and hernia defect size since these factors could also affect the risk of reoperation [23,24,27]. There was no significant relationship between the risk of reoperation and annual surgeon volume in the open mesh and open non-mesh cohorts, this could be because there is no clinical association. However, it could also be that the statistical power was not great enough to detect a significant difference due to type II errors.

Study IV: Risk of reoperation after elective primary groin and ventral hernia repair by supervised residents [4]

Background and aim

The previous studies in this thesis showed a significantly higher risk of reoperation after Lichtenstein, laparoscopic TAPP primary groin hernia repair, and laparoscopic repair of primary ventral hernias performed by low-volume compared with high-volume surgeons [2,3]. Furthermore, many of the low-volume surgeons in our population were still in their residency, and we found it necessary to investigate how outcomes for patients were affected when hernia repairs were used with the purpose of surgical training.

The aim of this study was to evaluate how the risk of reoperation was affected after primary groin, umbilical, and epigastric hernia repairs, when the repair was carried out by supervised trainees compared with specialists.

Methods

This nationwide register-based study was based on both the Danish Inguinal and Ventral Hernia Databases [80,81] and linked with data from the Danish Patient Safety Authority's Online Register [85]. The study period went from January 2016 to September 16, 2021, where data were extracted. Patients were followed until reoperation, death, emigration, or the end of the study period. Reoperation was defined as an operation for a recurrent hernia of the same type and same location after the index operation. Data were restructured so we considered hernia repairs for inclusion and not patients. We included all surgeons with a valid authorization ID registered. We included elective primary inguinal, femoral, umbilical, and epigastric hernia repairs performed in adult patients with either open or laparoscopic approach, performed by supervised residents or specialists. The primary outcome was reoperation rate due to recurrence for supervised residents compared with specialists, defined as surgeons with specialty in gastrointestinal or general surgery and who were not supervised. Risk of reoperation for recurrence was assessed with Cox Proportional Hazard Analyses separately for Lichtenstein groin, TAPP groin, open ventral, and laparoscopic ventral hernia repair, and covariates for the multivariate analyses were chosen upon a theory-based approach.

Results

We included 868 surgeons, performing 31,683 elective primary groin and 7,777 elective primary ventral hernia repairs. The adjusted Cox regression showed no significant changes in risk of reoperation (HR [95% CI]) after Lichtenstein primary groin (1.26 [0.99–1.59]), TAPP primary groin (1.01 [0.73–1.40]), open primary ventral (0.89 [0.61–1.29]), and laparoscopic primary ventral hernia repair (2.96 [0.99–8.84]) performed by supervised residents compared with specialists. Conversion rates from laparoscopic to open approach during primary groin and primary ventral hernia repair, respectively, did not vary significantly between supervised residents and specialists.

Conclusion

We found that elective open and laparoscopic repair of primary groin and ventral hernias by supervised residents were not associated with significant changes in risks of reoperation due to

recurrence, indicating that it is safe for residents to perform elective hernia repair under supervision as part of the surgical training.

Strengths and limitations

In contrast to study II and III [2,3], this study only included repairs performed after 2016 where the supervision variable became a required entry in the Danish Hernia Databases. Thus, limiting selection bias because we did not know what led surgeons or residents to fill out the supervision variable before it became a required entry. This study included both primary groin and primary ventral hernia repairs and represents an extensive work since it required data from both the Danish Inguinal and Ventral Hernia Databases. It was relevant to assess both groin and ventral hernia repair in our population of surgeons since both are a part of the Danish surgical training curriculum [118], as other countries like USA [119]. We used reoperation due to recurrence as an outcome measure for long-term quality of hernia repair. Ventral hernia repairs performed concomitant to other procedures were excluded since these procedures were for the most part performed by specialists, thus not representative of the primary ventral hernia repairs carried out with a training purpose. Furthermore, there is no evidence on how resident-involvement impacts the outcomes after concomitant ventral hernia repair.

The covariates included in the Cox regressions for risk of reoperation were chosen theory-based on our specific research question [92] which reduced the risk of overfitting the models with too many covariates that did not in fact impact risk of reoperation which in turn could give misleading results in the models [117]. For both primary groin and open ventral hernia repair, we chose to adjust for patients' age and hernia defect size. Patients' age can affect the risk of reoperation since there are many factors to consider in older patients, making them more complicated [12,22], furthermore, surgeons are probably more likely not to reoperate older patients. Hernia defect size is a proven predictor for recurrence after open ventral hernia repair [24]. Hernia defect size has not been proven a risk factor for recurrence after groin hernia repair [20], however, techniques still vary depending on the defect size. The risk of reoperation after primary groin hernia repair was also adjusted for the type of groin hernia (inguinal lateral, medial, or femoral) since the type of groin hernia could affect the risk of recurrence [20]. Open ventral hernia repair was also adjusted for BMI and smoking status since increased BMI and active smoking status, independently, have been associated with an increased risk of recurrence [23,24]. Former smoking and active smoking status seem to have a similar cumulated risk of recurrence after ventral hernia repair [24]. However, the smoking status variable in the Danish Ventral Hernia Database does not allow this distinction since it is dichotomized into active or

non-active smoker, leading to a risk of differential misclassification bias of non-active smokers. Open ventral hernia repair was also adjusted for mesh versus no mesh since mesh repairs has a reduced risk of recurrence compared with sutured non-mesh repairs [25]. Laparoscopic ventral hernia repair was adjusted for defect closure since it has been associated with lower rates of recurrence [27], and only one covariate was included in this Cox regression since there were only 20 events in this cohort [93]. Through study I–III of this thesis we showed that annual surgeon volume also affects the risk of recurrence-related reoperation [1–3]. However, annual surgeon volume was not included in the analyses of this study because we deemed annual surgeon volume to be an effect modifier [120] since supervised residents more likely had a low volume while specialists more likely had a higher annual volume. To take annual surgeon volume into account as an effect modifier, we could have stratified the Cox regressions based on annual surgeon volume to see the effects of different volume categories. However, it is uncertain that our study population included enough observations and events to reach sufficient statistical power had we chosen to stratify the Cox regressions in this study based on annual surgeon volume.

The importance of transparency in the reporting of supervision has been emphasized [121], however, this study was limited by the data availability in the Danish Hernia Databases and the dichotomized nature of the supervision variable. This allowed us to quantify supervision as the number of supervised residents. However, it did not allow us information on the quality of supervision like whether the supervising surgeon was a senior resident or specialist; if the supervising surgeon scrubbed in or not; or if the entire procedure or just critical points were supervised. The quality of supervision was outside the scope of this study, but it would be meaningful to assess the quality of supervision and the effects on the outcomes after primary hernia repair. Furthermore, we did not have access to information on whether specialists were assisted by residents and thus, it was not possible to assess the outcomes of resident-assisted hernia repairs although these repairs also make out a part of residents' training. Additionally, it would have been useful to assess residents' postgraduate year in this study since this term is used frequently as a measure of training level in the literature, and it would have increased the external validity of this study. However, we deemed that it was not possible to assess residents' postgraduate year since the Danish Patient Safety Authority's Online Register only provides information on the date of graduation and specialization, and thus it was not possible to account for extensions of residency due to parental leave or other reasons.

Discussion

The studies in this thesis investigated how annual surgeon volume and supervision of residents affected the recurrence-related reoperation rate after primary groin and primary ventral hernia repair, respectively. We found that annual surgeon volume seemed to impact the recurrence and reoperation rates after both primary groin and ventral hernia repair in the previously published literature [1]. Through register-based studies, we found a significantly higher risk of recurrence-related reoperation after Lichtenstein and laparoscopic TAPP repair of primary groin hernias [2] as well as laparoscopic repair of primary umbilical and epigastric hernias [3] performed by low-volume compared with high-volume surgeons. Lastly, we showed that supervised residents can perform elective open and laparoscopic repair of primary groin and ventral hernias without increased risk of reoperation compared with specialists [4].

Reoperation as outcome measure

Recurrence is often used as outcome measure for the surgical intervention in hernia repair [15], and it can be assessed by clinicians or the patients themselves. However, it is rather time consuming and costly to evaluate recurrence for each patient in large cohort studies. Therefore, reoperation is often used as a proxy for recurrence. Reoperation is practical to account for through registries such as the Danish Hernia Databases that are linked with the Danish National Patient Registry [78]. Yet, reoperation rates substantially underestimates the clinical recurrence rates after both groin and ventral hernia repair [16,17]. This could lead to an underestimation of the rates and risks of reoperation we found in studies II–IV [2–4]. If patients with recurrences who were not reoperated were equally distributed in the different volume categories, it would give rise to a non-differential misclassification bias which would not affect our rates or risks of reoperation. The time to follow-up was limited by study periods in studies II–IV [2–4] which in turn was limited by when authorization ID became a required entry in the Danish Hernia Databases. A previous study showed that patients had to be followed for 20–50 years before the majority of groin hernia recurrences had occurred [105]. Due to our relatively short follow-up period, it is likely that recurrences could occur in the future, possibly underestimating the relation between recurrence-related reoperation and annual surgeon volume. In our population, the median age of groin hernia patients was between 58–69 years [2,4], so even if our study population was followed for 20–50 additional years the reality is that most of the patients would probably have died or deemed too old for a reoperation. For ventral hernias, almost all

recurrences have occurred within four years [116] and, thus, the follow-up times for the ventral hernia repairs included in the studies of this thesis were sufficient [3,4].

Recurrence or reoperation are important outcome measures for surgeons and researchers as it also implies if the repair was successful. There are also other outcome measures after hernia repair to consider, and some outcomes might be more important or relevant to the patients undergoing hernia repair. This could be pain, physical impairment, physical appearance, social aspects, and satisfaction with surgeons and staff [122]. These outcomes could be evaluated with questionnaires, assessment by clinicians or investigators, or interviews, shedding light on the impacts on patients' quality of life, this would arguably be more time consuming and costly for researchers. In addition, a recent qualitative study showed that abdominal wall hernias have negative impacts on patients' mental health, causing psychological and emotional distress along with identity disruption [123]. However, mental health is an often-overlooked domain in quality of life in research. It is important to tailor research to also include factors important to the patients undergoing hernia repair with patient-centered outcome measures taking quality of life and chronic pain into account. The studies included in this thesis were limited by the data available in the Danish Hernia Databases, causing us to use reoperation for recurrence as the primary outcome measure.

Balancing surgical outcomes and training

Hernia repair is a common procedure [5,6] also with residents as the primary operator [124], and it is often part of the surgical training curriculum. Surgical training requires that residents learn skills by participating or assisting in procedures, gradually taking on more responsibility and continuously developing their practical skills while receiving supervision and feedback [125]. A persisting dilemma in the surgical specialties is how to balance patient outcomes and training, and although resident-involvement in general surgery has been associated with longer operation times, it is not necessarily associated with higher complication or mortality rates [126].

Study IV [4] of this thesis showed that supervised residents can safely perform elective repairs of primary groin and ventral hernias without increased risk of reoperation compared with specialists. This is in line with previous studies for open and laparoscopic groin hernia repair [127,128], and a more recent retrospective study showed that supervised trainees were not associated with higher rates of postoperative complications, recurrence, or chronic pain compared with consultants after TEP repair of groin hernia repairs [129]. However, the literature on the effects of supervision in primary ventral hernia repair is limited. A retrospective register-

based study showed that trainee involvement in laparoscopic repair did not lead to increased reoperation rates but was associated with significantly longer operative times compared with attendings alone, however they only included incisional hernias [130]. Another retrospective study found no differences in mortality and recurrence rates after incisional hernia repair performed by consultant-assisted trainees compared with consultants alone [131]. However, a large register-based study showed increased operative times and risks of reoperation associated with supervised trainees after open primary inguinal hernia repair compared with specialists [29]. Yet, as the authors point out, this implies the need for guidance of trainees to ensure they reach surgical autonomy and not that trainees should be excluded from partaking in open inguinal hernia repair. Study IV also showed that only approximately 8% of laparoscopic repairs of both primary groin and ventral hernias, respectively, were performed by supervised residents [4]. Similarly, a study found that despite increasing number of inguinal hernia repairs performed laparoscopically, resident involvement and autonomy has declined significantly [132] which is also the case in many other procedures commonly used in resident training [124]. This could pose a challenge, regarding the training potential in laparoscopic hernia repairs.

Ensuring optimal outcomes for patients whilst ensuring sufficient surgical training should continue to be a focus point, and supervision is a key point here. A Danish randomized study showed that a combination of a skills lab and 20 supervised Lichtenstein groin hernia repairs during the first year of surgical training led to shorter operation times and increased surgical proficiency and technical skills compared with a conventionally trained group [133]. This is encouraging, and underlines the beneficial effects of combining supervision with other teaching modalities, and the opportunities of simulation-based training to supplement traditional training in hernia repair are increasing [134]. Along with supervision, an adequate caseload is necessary for residents and surgeons to overcome the learning curves in hernia repair [13,33,34]. There are several national curricula in place to ensure adequate training and caseload during training programs. These curricula range from 10 competency evaluated groin and ventral hernia repairs in Denmark [118], 25 hernia repairs in Germany [135], 50 inguinal hernia repairs in the UK [136], to 85 groin and ventral repairs in USA [119]. Yet, it is unclear how these curricula are used in the clinical setting and if they are upheld. As one study of trainee logbooks showed, residents do not perform enough laparoscopic inguinal hernia repairs to overcome their learning curve in USA and Australia [137]. Additionally, it is unclear in most of the curricula if these repairs need to be supervised. In Denmark, the competency evaluated hernia repairs are supervised, still 10 supervised groin and ventral hernia repairs, respectively, are not sufficient to overcome most of the learning curves [13,33,34]. Although supervised residents can perform

hernia repair with safe patient outcomes, the reality is that residents might not achieve the required caseload of hernia repairs to overcome their learning curve. In combination with the increasing complexity of abdominal wall repair [138], it does not necessarily mean that residents can perform hernia repair independently after completing their residency.

Centralization of hernia repair

Centralization in this thesis refers to centralization on fewer surgeons since the studies included in this thesis underlines benefits of centralization of hernia repair on fewer surgeons [1–3]. A protective effect of high surgeon volume was also found in other procedures such as cholecystectomy, where high-volume surgeons were associated with shorter operative times and a lower risk of conversion from laparoscopic to open approach [38]. Low annual surgeon volume ≤100 cases/year led to significantly increased risks of reoperation after open and laparoscopic repair of primary groins hernia compared with annual surgeon volume >100 cases/year [2]. Other studies, included in our systematic review [1], have also shown reduced risks of reoperation after groin hernia repairs performed by high-volume surgeons compared with low-volume surgeons for both open [101,103,104] and laparoscopic [102–104,139] repairs. Since the publication of our systematic review a large cohort study has been published, investigating the risk of reoperation after inguinal hernia repair in association with surgeon volume [140]. This study found a significantly reduced risk of reoperation after laparoscopic inguinal hernia repairs performed by high-volume surgeons, with >27 annual repairs, compared with low-volume surgeons [140]. Thus, these findings show a similar pattern as our findings in studies I and II after laparoscopic inguinal hernia repair [1,2]. There were varying definitions of high annual surgeon volume from ≥25 [101,102] to >60 cases/year [104] in the existing literature, making it difficult to compare these high-volume groups with ours. When designing our annual volume categories for groin hernia repair in study II, we deemed it necessary to implement more categories to better evaluate the effects of annual surgeon volume. Interestingly, after open repair the crude reoperation rate seemed increased for surgeons with an annual volume of 26–50 and 51–100, whilst decreasing for annual volume >100 cases/year [2]. Differences like these are not apparent in the previous studies because of the volume category definitions, limiting the distinguishments of annual surgeon volume's effect on risk of recurrence. Perhaps this difference could be explained by differences in follow-up time across the volume categories, or perhaps there are other factors in play. Only one study had previously investigated the impact of annual surgeon volume on risk of reoperation after primary ventral hernia repair, and found reduced risk

of reoperation after primary ventral hernia repairs performed by high-volume surgeons compared with low-volume surgeons [96]. This is in line with our findings for laparoscopic primary ventral hernia repair in study III [3], as we used the same volume categories to make it comparable. A more recent cohort study showed that a total high operative experience >100 procedures was associated with a reduced risk of recurrence after complex abdominal wall repair compared with low total experience, in a heterogenous cohort with both primary and recurrent ventral hernias [141]. However, we deliberately excluded complex ventral hernias in study III [3] since these were rare in our population and the surgical approach is different and more complex. Another large register-based study found a reduced risk of reoperation after incisional hernia repairs performed by high-volume compared with low-volume surgeons [142]. Again, these findings are not comparable with our study findings since we excluded incisional hernias [3].

Centralizing hernia repair would mean a centralization of the experience on fewer surgeons, thus allowing surgeons to reach and maintain a higher annual volume which could lead to better outcomes for patients, regarding risk of reoperation, as shown in this thesis [1–3]. Furthermore, high annual surgeon volume has been associated with shorter operative times in groin hernia repair [21,101,139] which in turn could reduce the risk of postoperative complications [21]. Thus, there is evidence supporting that centralization of hernia repairs would benefit patients by reducing unwanted complications. In addition, the complexity of abdominal wall repair is increasing [138], and centralization of hernia repairs would arguably also benefit surgeons performing hernia repairs. It would allow them to build and maintain the acquired annual volume to ensure better outcomes. The HerniaSurge Group's guidelines for groin hernia repair underlines the importance of specialization in hernia repair for both centers and surgeons to better postoperative outcomes for patients. However, the evidence was of low grade [12]. One study found that the variation in annual surgeon volume explained more variation in reoperation rates than the center volume after both inguinal and primary ventral hernia repair [96], thus an argument for centralization of hernia repair on surgeons rather than centers. The Accreditation and Certification Centers and Surgeons (ACCESS) group, appointed by the European Hernia Society, suggested that an accredited or certified hernia center should perform a significantly higher number of cases annually compared with the average general surgery department. The ACCESS Group also suggested that national societies develop requirements for a minimum center caseload, encouraging national societies to offer a minimum caseload to the individual surgeons based on the literature [143]. Based on the findings in this thesis, these minimum requirements would be 100 cases/year for Lichtenstein and TAPP primary groin hernia repair and 30 cases/year for laparoscopic primary ventral hernia repair to reduce the risk of

reoperation [2,3]. The European Union of Medical Specialists (UEMS) has made it possible to become certified in abdominal wall repair for surgeons [144], requiring 200 inguinal, 50 ventral, and 50 incisional or complex hernia repairs [145]. However, it is not specified if this is in total over surgeons' carrier or if it is over a certain period, and it is questionable if it would be sufficient if the requirements refer to procedures performed throughout an entire carrier. In Denmark, there are currently no official guidelines for what constitutes a hernia specialist. Only parastomal hernias and giant hernias (hernia defect size >10 cm) are centralized on five specialized hernia centers, one in each of the five national regions [146]. After this centralization of parastomal hernia repair, more patients were offered surgery and the number of older patients and patients with larger defects who underwent surgery increased [147]. Although more complex patients underwent surgery for parastomal hernias, there was no increase in the risk of postoperative complications [147], indicating beneficial effects of centralization of parastomal hernia repair. A recent survey of members from the Americas Hernia Society showed varying choices in component separation and choice of mesh depending on surgeons' experience, indicating a need for national guidelines for hernia repair and specialized hernia care [148].

There are also impeding factors on the feasibility of centralization of general surgery procedures such as hernia repair. With centralization, training and education in hernia repair would be carried out by fewer surgeons, necessitating the fewer surgeons performing hernia repair to undertake the responsibility of education and training, also of external surgeons and residents [143]. Furthermore, centralization on fewer surgeons could lead to geographical challenges since it would require some patients to travel greater distances to reach a center with high-volume surgeons. Lastly, hernia repair is for the most performed electively, however, some patients present with acute indication for surgery due to incarcerated or strangulated hernia [149], and a study from the Danish Hernia Database showed high mortality and reoperation rates after emergency groin hernia repair [150]. It might be worth considering how emergency hernia repairs are handled if hernia repair is centralized. Neither the suggestions from the ACCESS Group [143] nor guidelines on certified hernia centers from Germany [151] consider emergency hernia repair . In our study population, low-volume surgeons operated significantly more emergency primary groin and ventral hernias compared with high-volume surgeons [2,3]. Published guidelines for both groin and ventral hernia repair suggest a patient-tailored approach in emergency repairs [12,13], and it seems fair to assume that a patient-tailored approach would require a high annual surgeon volume or high surgical experience. Therefore, it is worrisome that the majority of emergency hernia repairs were performed by lower volume surgeons [2,3].

Conclusion

This thesis investigated how surgical experience, measured as annual surgeon volume and supervision, affected the recurrence-related reoperation rate after hernia repair. We found a tendency of higher recurrence or reoperation rates after both groin and primary ventral hernia repairs performed by low- compared with high-volume surgeons in the existing literature. There was a higher risk of recurrence-related reoperation after open and laparoscopic primary groin, as well as laparoscopic primary umbilical and epigastric hernia repairs performed by lower volume surgeons compared with high-volume surgeons. Our findings suggest a beneficial effect of centralization of open and laparoscopic repair of primary groin hernia repair, as well as laparoscopic primary ventral hernia repair on fewer surgeons. Lastly, we found that elective open and laparoscopic repair of primary groin, umbilical, and epigastric hernias performed by supervised residents were not associated with higher risks of recurrence-related reoperation compared with specialists, indicating that supervised residents can safely perform hernia repair as part of their training.

Perspectives and future studies

Studies included in this thesis showed beneficial effects of centralization of hernia repair on fewer surgeons, regarding reoperation rates [1–3]. In Germany, it is possible to become a certified hernia center [151], and in Italy the first steps towards a hernia certification has been taken with a consensus of individual annual surgeon volume of >100 cases/year [152]. Is it time for national requirements or guidelines for hernia surgeons in Denmark? Perhaps national guidelines with a minimum required annual volume or accreditation of hernia surgeons might benefit and ensure adequate outcomes for patients, and it would allow surgeons to maintain a sufficient annual volume. There might also be a need for requirements of training and education of residents, even from external departments. However, national requirements for annual surgeon volume could mean that there would not be enough hernia repairs for all residents to overcome learning curves. We did not include the repairs where surgeons were the supervisor in the calculations of annual volume since this was not possible [2,3], thus we are unable to say how the risk of reoperation would be affected if the repairs performed as supervisor were included in the surgeon volume calculation. To our knowledge this has not yet been investigated in the existing literature. By introducing the benefits of centralization of hernia repair on fewer surgeons, it inevitably will raise the question of who has to learn how to perform

hernia repairs. Considering that residents are not meeting the required number of laparoscopic repairs, according to national curricula and to overcome their learning curves [137], outcomes after these repairs might have benefitted if they were performed by high-volume surgeons instead. The ACCESS Group appointed by the European Hernia Society has formulated requirements for certified hernia centers that national societies can use to formulate guidelines [143], however, these do not include requirements regarding emergency hernia repair.
A questionnaire among Danish surgical departments performing emergency groin hernia surgery showed a mismatch between the wish and the possibilities of surgical departments' emergency teams to offer laparoscopic emergency groin hernia repair, partly due to surgeons' experience [153]. Guidelines from the Danish Colorectal Cancer Group state that surgical treatment of colon ileus should be performed with a specialized colorectal surgeon present [154], as specialized colorectal surgeons have been associated with lower risk of anastomotic dehiscence, postoperative complications, and mortality [155]. However, the literature on annual surgeon volume's effect on outcomes after emergency hernia repair is limited. A simulation study of the effect of hospital regionalization of emergency surgery showed a prevention of death in 8 out of 100 patients in umbilical hernia and 6 out of 100 patients in inguinal, femoral, and ventral hernia repair [156]. There are implications for further research investigating if there is a need for centralization of emergency hernia repair on fewer surgeons which could be carried out in registers like the Danish Hernia Database.

The primary outcome measure in the included studies of this thesis was reoperation due to recurrence. However, as discussed in this thesis, other outcomes might be more important to patients' well-being and mental health [122,123]. This implicates further research of the effects of annual surgeon volume and supervision on patient-centered and patient reported outcome measures for quality of life, including chronic pain to see if there would still be an effect of annual surgeon volume and supervision. This would entail patients filling out questionnaires. The Swedish Hernia Register includes patient reported outcome measures by sending out questionnaires to patients by mail one year after surgery [157], and a study from the Swedish Hernia Register actually showed a mismatch between registered postoperative complications in the register and complications reported by patients in questionnaires after groin hernia repair, resulting in underreporting of complications in the register [158]. One study from the Swedish Hernia Register found that low annual surgeon volume of ≤5 cases/year did not influence chronic pain significantly [159]. However, it is not possible to conclude if high annual surgeon volume is associated with a decreased or unchanged risk of chronic pain since the study did not report on high annual surgeon volume.

In this thesis, we showed the effects of supervision on reoperation rates [4]. However, it was not possible to investigate how residents were supervised through the Danish Hernia Database. A point for transparency in reporting of supervision has been made [121]. In theory, this could be achieved, even in register-based study designs with more thorough variables, providing information like who the primary operator was; authorization ID of the supervising surgeon which would give information about their experience; and a stratification or differentiation of the degree of supervision. Furthermore, variables allowing researchers to see if the repairs were assisted, and if yes, the assistant's authorization ID could be useful to see how residents are involved in repairs when they are not the primary operator. The studies in this thesis calculated annual volume based on repairs where the surgeon was the primary operator [2,3], but variables with information about assisting surgeons would have allowed us to take this into account in our annual volume calculations which could perhaps have been meaningful. Since the number of repairs where surgeons assisted might also affect their experience and the outcomes measured after hernia repair. Other steps to assess the quality of supervision in hernia repair through surveys, questionnaire, or interviews could be taken. It could be relevant to investigate if residents are receiving effective supervision, and what constitutes effective supervision in their eyes, and if supervisors feel they are giving effective supervision, and what they associate with good supervision. This would allow identification of potential mismatches between the perception of supervision between those being supervised and those supervising.

English summary

Background

Both groin and ventral hernia repairs are common procedures with 13–15,000 hernia repairs each year in Denmark. Primary inguinal hernia repair has a reoperation rate of 8% and the recurrence rate after primary ventral hernia repair has been reported as high as 15% in the Danish Hernia Database. There are many known risk factors for recurrence or reoperation after both primary groin and ventral hernia repair such as patients' age, body mass index, hernia defect size, use of mesh, and defect closure during laparoscopic ventral hernia repair. In addition, the operating surgeon's experience also seem to affect the risk of recurrence with a study showing a higher risk of recurrence after inguinal hernia repairs performed by unsupervised trainees. However, existing literature on the impact of surgeons' experience on the recurrence rate after hernia repair is limited and the evidence is of low grade. Thus, research investigating the effects of surgeons' experience on the risk of recurrence or reoperation after both groin and ventral hernia repair is needed.

The studies in this thesis investigated how annual surgeon volume and supervision affected the recurrence-related reoperation rates after primary groin and ventral hernia repairs.

Methods and results

This thesis includes four studies: a systematic review and three register-based studies, using data from the Danish Inguinal and Ventral Hernia Databases linked with data from the Danish Patient Safety Authority's Online Register. The patients included were adult patients undergoing open or laparoscopic repair of primary groin or ventral hernias. The primary outcome measure was reoperation for recurrence after hernia repair as a proxy for the recurrence rate.

Study I was a systematic review investigating how annual surgeon volume and total surgical experience affected outcomes after groin, as well as primary umbilical and epigastric hernia repair, in the previous published literature. We included 10 records, based on seven studies. Five studies showed a tendency of higher recurrence or reoperation rate after groin hernia repairs performed by low-volume surgeons in comparison with high-volume surgeons. One study showed a decreased reoperation rate after primary umbilical and epigastric hernia repair when performed by high-volume compared with low-volume surgeons.

Study II was a cohort study based on the Danish Inguinal Hernia Database that investigated the effects of annual surgeon volume on the reoperation rate for recurrence after primary groin

hernia repair. We found a higher risk of reoperation after primary groin hernia repairs performed by low- and medium-volume compared with high-volume surgeons for both Lichtenstein and laparoscopic groin hernia repair.

Study III was based on data from the Danish Ventral Hernia Database that investigated the effect of annual surgeon volume on the reoperation rate for recurrence after primary umbilical and epigastric hernia repair. We found an increased risk of reoperation after laparoscopic repair of primary umbilical and epigastric hernia repairs performed by low- and medium-volume surgeons compared with high-volume surgeons.

Study IV was based on data from the Danish Inguinal and Ventral Hernia Databases and evaluated how the risk of reoperation was affected after primary inguinal, femoral, umbilical, and epigastric hernia repairs, when the repairs were carried out by supervised residents compared with specialists. We found that elective open or laparoscopic repair of primary groin or ventral hernias by supervised residents was not associated with changes in the risk of reoperation due to recurrence.

Conclusion

Study I showed that a high annual surgeon volume seemed to reduce rates of recurrence and reoperation after both groin and primary ventral hernia repair in the previously published literature. Studies II and III showed that high-volume surgeons had lower risks of recurrence-related reoperation after open and laparoscopic repair of primary groin hernias, as well as laparoscopic primary umbilical and epigastric hernias. These findings indicate a need for centralization of primary hernia repair on fewer surgeons, allowing them to build and maintain a higher annual surgeon volume. Study IV showed that supervised residents can perform elective open and laparoscopic repair of primary groin and ventral hernias without increased risk of reoperation. This suggests that elective primary hernia repair can safely be part of residents' surgical training.

Dansk resumé

Baggrund

Både lyskenære og ventrale hernier er hyppigt forekommende hernier, og i Danmark opereres mellem 13–15.000 patienter årligt. Primære ingvinalhernier har en reoperationsrate på 8 %, mens recidivraten efter primære ventralhernier er 15 %. Der er flere kendte risikofaktorer for recidiv eller reoperation efter operation for både primære lyskenære og ventrale hernier, såsom patientens alder, vægt, herniedefektens størrelse, brug af mesh og suturlukning af herniedefekten under laparoskopi for ventralhernier. Derudover lader kirurgens erfaring også til at påvirke risikoen for reoperation for recidiv, da et tidligere studie fandt en øget risiko for recidiv efter ingvinalhernieoperationer udført af usuperviserede kirurger under uddannelse. Den eksisterende litteratur, om effekten af kirurgers erfaring på risikoen for recidiv, er dog begrænset. Derfor er der brug for studier, som undersøger hvordan kirurgers erfaring påvirker risikoen for recidiv efter operationer for både lyskenære og ventrale hernier.

Studierne i denne afhandling havde til formål at undersøge, hvordan kirurgers årlige operationsvolumen, samt supervision af kirurger under uddannelses, påvirkede reoperationsraten efter operationer af henholdsvis primære lyskenære og ventrale hernier.

Metoder og resultater

Denne afhandling indeholder fire studier: et systematisk review og tre registerbaserede kohorte studier, der inkluderede data fra dansk Herniedatabase, der blev koblet med data fra Sundhedsstyrelsens Autorisationsregister. Vi inkluderede voksne patienter, opereret for et primært lyskenært eller ventralt hernie med enten åben eller laparoskopisk teknik. Det primære endemål var reoperationsraten, der blev brugt som proxy for recidivraten.

Studie I var et systematisk review, der undersøgte, hvordan kirurgers årlige og samlede operationsvolumen påvirkede recidivraten efter operationer af både lyskenære og primære ventrale hernier, i tidligere publiceret litteratur. Vi inkluderede 10 videnskabelige artikler. Fem studier viste en tendens til højere recidivrate for lyskenære hernier opereret af kirurger med et lavt årligt operationsvolumen i forhold til et højt årligt operationsvolumen. Et studie viste en lavere reoperationsrate efter primære ventralhenier opereret af kirurger med et højt årligt operationsvolumen, sammenlignet med et lavt operationsvolumen.

Studie II var et kohortestudie baseret på data fra den danske Ingvinal Herniedatabase, der undersøgte hvordan kirurgers årlige operationsvolumen påvirkede risikoen for reoperation af primære lyskenære hernier. Vi fandt en signifikant højere risiko for reoperation, når de

lyskenære hernier blev opereret af kirurger med lavt eller intermediært årligt operationsvolumen, sammenlignet med et højt operationsvolumen, for både åben og laparoskopisk teknik.

Studie III var baseret på data fra den danske Ventral Herniedatabase, og undersøgte effekten af kirurgers årlige operationsvolumen på den recidivrelaterede reoperationsrate efter kirurgi for primære ventrale hernier, det vil sige umbilikale og epigastrielle hernier. Vi fandt en øget risiko for reoperation efter laparoskopiske operationer af primære ventrale hernier udført af kirurger med et lavt eller intermediært årligt operationsvolumen, sammenlignet med et højt operationsvolumen.

Studie IV var baseret på data fra både den danske Ingvinale og Ventrale Herniedatabase, og vurderede risikoen for reoperation efter henholdsvis primære lyskenære og ventrale hernier, når operationen blev udført af superviserede uddannelseslæger sammenlignet med speciallæger i kirurgi. Dette studie viste, at elektive åbne og laparoskopiske operationer, for både primære lyskenære og ventrale hernier, udført af superviserede uddannelseslæger, ikke var associeret med øget risiko for reoperation sammenlignet med operationer udført af speciallæger.

Konklusion

Studie I viste, at et højt årligt operationsvolumen syntes at reducere recidiv- og reoperationsraten efter både lyskenære og primære ventrale hernieoperationer i den tidligere publicerede litteratur. Studie II og III viste, at kirurger med et højt årligt operationsvolumen var associeret med en lavere risiko for reoperation efter åben og laparoskopisk kirurgi af primære lyskenære hernier, samt laparoskopisk kirurgi af primære umbilikale og epigastrielle hernier. Dette indikerer et behov for centralisering af primær herniekirurgi på færre kirurgers hænder, så de kan opbygge og opretholde et højt årligt operationsvolumen. Studie IV viste, at superviserede uddannelseslæger kan udføre elektiv åben og laparoskopisk kirurgi af primære lyskenære og ventrale hernier uden øget risiko for reoperation, sammenlignet med speciallæger. Dette indikerer, at elektiv primær herniekirurgi kan indgå i den kirurgiske uddannelse, uden at medføre risici for patienter.

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Full-text studies included in the PhD thesis

Study I — Christophersen C, Fonnes S, Andresen K, Rosenberg J. Lower recurrence rate after groin and primary ventral hernia repair performed by high-volume surgeons: a systematic review. Hernia 2022;26:29–37 [1].

Study II — Christophersen C, Baker JJ, Fonnes S, Andresen K, Rosenberg J. Lower reoperation rates after open and laparoscopic groin hernia repair when performed by high-volume surgeons: a nationwide register-based study. Hernia 2021;25:1189–1197 [2].

Study III — Christophersen C, Fonnes S, Baker JJ, Andresen K, Rosenberg J. Surgeon volume and risk of reoperation after laparoscopic primary ventral hernia repair: a nationwide register-based study. J Am Coll Surg 2021;233:346–356 [3].

Study IV — Christophersen C, Fonnes S, Andresen K, Rosenberg J. Risk of reoperation for recurrence after elective primary groin and ventral hernia repair by supervised residents. JAMA Surg 2023;158:359–367 [4].

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REVIEW

Lower recurrence rate after groin and primary ventral hernia repair performed by high-volume surgeons: a systematic review

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Abstract

Purpose Hernia repair is a common procedure; however, an overview is lacking regarding the impact of annual surgeon volume and total surgical experience on the outcome of hernia repair. We aimed to explore the impact of annual surgeon volume and total surgical experience on outcomes of groin and primary ventral hernia repair.

Methods This systematic review followed the Prefered Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline. A protocol was registered at PROSPERO (CRD42020176140). PubMed, EMBASE, and Cochrane CENTRAL were searched. We investigated recurrence rates after groin and primary ventral hernia repair reported according to annual surgeon volume or total surgical experience with at least 6 months follow-up. Surgeons were pooled in three overlapping categories: high-volume (> 50 cases/year), medium-volume (11–50 cases/year) and low-volume (≤ 25 cases/year).

Results Ten records for groin hernia and one for primary ventral hernia were included. The median (range) recurrence rates after laparoscopic groin hernia repair for high, medium, and low-volume surgeons were 2.6% (2.3–3.0), 2.4% (0.7–4.6), and 4.2% (1.0–6.8), respectively. The median (range) recurrence rate after open groin hernia repair for high, medium, and low-volume surgeons were 2.1% (2.0–2.2), 1.7% (1.6–2.3), and 2.4% (2.2–5.0). The groin hernia recurrence rate seemed to increase when annual surgeon volume decreased below 25 cases/year. For primary ventral hernia, increased annual surgeon volume was associated with decreased reoperation rate.

Conclusion High-volume surgeons seemed to have lower rates of hernia recurrence after groin as well as primary ventral hernia repair and our data supports the need for centralization of groin hernia repair on individual surgeons.

Keywords Hernia · Surgeon volume · Surgical experience · Recurrence · Reoperation

Introduction

Groin hernia repair is a common procedure, and each year approximately 20 million groin hernias are repaired worldwide [1]. The reoperation rate for groin hernia is about 5% [2], and is often used as a proxy for surgical quality, however, the true recurrence rate is expected to be approximately 40% higher than the reoperation rate for groin hernia [3]. Likewise, only 30% of recurrences after umbilical and epigastric hernia repair are reoperated [4]. There are many known risk factors for hernia recurrence. The patient-related risk factors include age, sex, BMI, and smoking status [5]. The surgeon related risk factors include the choice of surgical technique [6, 7], choice of mesh [8], and the duration of the operation [9]. Previous studies have shown that high annual surgeon volume and total surgical experience may have a beneficial impact on the duration of the operation, postoperative complication rate, and postoperative mortality for various procedures such as bariatric surgery [10], laparoscopic cholecystectomy [11], and pancreatic resection [12, 13]. Similar, the impact of total surgical experience on the outcome for groin hernia repair was studied in the Swedish Hernia Register [14], where surgical trainee involvement was shown to be a risk factor for recurrence-related reoperation. The literature on the relationship between annual surgeon volume and the recurrence rate after hernia repair is limited and a clear overview of the existing literature is

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needed. The HerniaSurge Group published international guidelines for groin hernia management that underlined the importance of guidelines regarding annual surgeon volume and total surgical experience. Thus, they have indicated that individual annual surgeon volume may be a more important factor for hernia repair outcome than hospital volume [15].

The aim of this systematic review was to explore the impact of annual surgeon volume and total surgical experience on the outcomes after groin, umbilical, and epigastric hernia repair.

Methods

This review was reported using the Prefered Reporting Items for Systematic Reviewas and Meta-Analyses (PRISMA) statement [16]. A protocol was registered at the PROSPERO website (Registration number: CRD42020176140) prior to data extraction [17].

Eligibility criteria

The target population was patients undergoing surgery for groin hernia with the open Lichtenstein technique, laparoscopically with totally extraperitoneal repair (TEP) or transabdominal preperitoneal repair (TAPP), and patients undergoing surgery for primary umbilical or epigastric hernia using sutured or mesh-based repair, with open or laparoscopic technique. We compared surgeons who had a high annual surgeon volume or high total surgical experience in hernia repair with surgeons who had a low annual surgeon volume or low total surgical experience in hernia repair. The main outcome was recurrence with a minimum median follow-up of six months, which had to be reported for both high-volume and low-volume surgeons or experienced and inexperienced surgeons. Randomized clinical trials and observational studies were considered for inclusion, while systematic reviews and case series with data on less than five surgeons were excluded. Studies were also excluded if they had no measure of individual annual surgeon volume or total surgical experience. Furthermore, studies were excluded if the outcome of hernia repair was not reported based on annual surgeon volume or total surgical experience. Finally, only records in English and the Scandinavian languages were considered for inclusion.

Search strategy

We searched PubMed (1966–present), EMBASE (1974–present), and the Cochrane CENTRAL. The final search was conducted on 5th of March 2020. The search strategy in short was hernia and either annual surgeon volume or total surgical experience. The full search strategy in PubMed was: (hernia) AND ("learning curve" OR surgeon volume* OR "surgeon's volume" OR surgical volume* OR operative volume* OR high-volume OR low-volume OR "repair volume" OR "surgeon's experience" OR surgical experience* OR "surgeon factors"). The search strategy was developed in cooperation with a professional research librarian and was modified to EMBASE and Cochrane CENTRAL [17]. Additionally, a snowball search of the included records' references was conducted [18].

Study selection and data extraction

Duplicate records were removed. The screening was carried out independently and in parallel by two reviewers. Initially, titles and abstracts were screened followed by a full-text screening. Disagreements on inclusion were resolved within the author group. Data were extracted twice from the included records by one of the reviewers into a predefined Excel spreadsheet in accordance with the PROSPERO protocol [17] and checked for accuracy.

The characteristics extracted from the included records were: authors, publication year, country, study design, number of patients, type of hernia, type of surgery, patient characteristics, the records' definition of high-, and low-volume surgeons along with experienced and inexperienced surgeons, and for each of these groups the number of surgeons and repairs performed. Additionally, the outcomes extracted were the recurrence or reoperation rate along with data on follow-up, 30-day postoperative mortality rate, 30-day readmission rate, and 30-day postoperative complication rate converted and reported according to the Clavien-Dindo classification [19] when possible.

Risk of bias assessment

The risk of bias was assessed independently and in parallel by two reviewers, and conflicts were resolved within the author group. The bias of randomized controlled trials was assessed using the Cochrane Risk of Bias tool [20] on the following five domains: selection, performance, detection, attrition, and reporting bias. Furthermore, the trials were assessed for other sources of bias. The bias of non-randomized studies was assessed using the Newcastle–Ottawa scale [21], evaluating the studies on three domains: selection, comparability, and outcome. The studies were graded from zero to nine stars with a low number of stars indicating a high risk of bias and vice versa. To meet the requirement of adequacy the studies had to report a minimum median time to follow-up of 6 months. The bias evaluation was based on the research question of this systematic review.

Summary measures and synthesis of results

Estimates for pooled recurrence rates or reoperation rates were calculated for groin hernia, but no estimates were calculated for umbilical and epigastric hernia since there was only one available study. Because of heterogeneity among the studies on groin hernia no meta-analysis was conducted.

High-volume and low-volume surgeons

We aimed to map the difference in recurrence or reoperation rate between high- and low-volume surgeons. The cut-off values for annual surgeon volume varied across the included studies, and there were varying definitions of high-volume and low-volume surgeons. Furthermore, several studies included groups of surgeons with intermediate annual surgeon volumes, and therefore we introduced a medium-volume category. For each study, the annual surgeon volume was pooled into three categories based on the findings of the included studies: high-volume, medium-volume, and low-volume surgeons. This enabled us to compare the recurrence or reoperation rate in relation to annual surgeon volume across the included studies. We defined high-volume surgeons as surgeons performing > 50 cases/year and low-volume surgeons as surgeons performing ≤ 25 cases/year, reflecting the general tendency in the definition and cut-off values across the studies. The medium-volume category was defined as a broad category to include the varying cut-off values for annual surgeon volume across the studies. The medium-volume category was defined as 11–50 cases/year. This resulted in an overlap between the medium and low-volume category for annual surgeon volume since not all studies had a cut-off at 25 cases/year.

Recurrence and reoperation rate

The outcome measure in the included records varied since both recurrence and reoperation rates were reported, and the two were therefore used equally in this review. For each study we re-estimated the recurrence or reoperation rate based on annual surgeon volume, pooling the surgeons in the abovementioned volume categories. For each study, data on recurrence and reoperation rates were pooled for open and laparoscopic repair separately. When data were available, the total number of recurrences or reoperations were divided by the total number of patients treated by the respective groups of surgeons in each study, according to the abovementioned volume categories. This resulted in a pooled recurrence rate within each study, according to the abovementioned categories for annual surgeon volume defined in this review. However, if a pooled rate could not be re-estimated for a study, the median recurrence or reoperation rate was estimated for the respective groups of surgeons.

The median of the pooled recurrence and reoperation rates were calculated across the studies for open and laparoscopic repair separately and presented with the ranges for high, medium, and low-volume surgeons, respectively. No formal statistical comparisons were performed.

Results

Study selection

Three databases were searched resulting in 2,756 records, and a total of ten records were included in this review [22–31]. The study selection process is depicted in the PRISMA flowchart in Fig. 1. Due to overlapping study populations, there were seven studies [22, 24, 26–29, 31], reported in eight records [22, 24–29, 31] with unique patient data on groin hernia and one study with unique patient data on umbilical and epigastric hernia [30]. There were overlapping study populations in two records from a retrospective database [28, 30], two records based on the Swedish Hernia Register [24, 25], and one record [23] reported on a subgroup originating from the already included randomized controlled trial [22]. The duplicate data on patients [23, 25, 30] were omitted from the total number of patients in this review.

Risk of bias within studies

The included randomized clinical trial [22] was assessed to have a high risk of bias. The selection bias, detection bias, attrition bias, and reporting bias were assessed as low risk of bias, and the performance bias was assessed as unclear risk of bias. However, there were other concerns of bias in this trial due to their use of different mesh sizes [32] which most probably affected the recurrence rate, and this resulted in a high risk of bias (Online Resource 1). The Newcastle–Ottawa scale was used to assess the risk of bias in the remaining included studies, which is shown in Table 1, and the median score (range) was seven (5–8) stars. Overall, there was a low to medium risk of bias. The included studies rated high in the selection domain and outcome domain, giving them a low risk of bias, however, the studies rated low in the comparability domain, leading to a medium risk of bias.

Groin hernia

Study characteristics

The characteristics of the included studies are presented in Table 1, and data on overlapping study populations were left out of the table. The definition of recurrent groin hernia varied across the included records as reoperation rate related

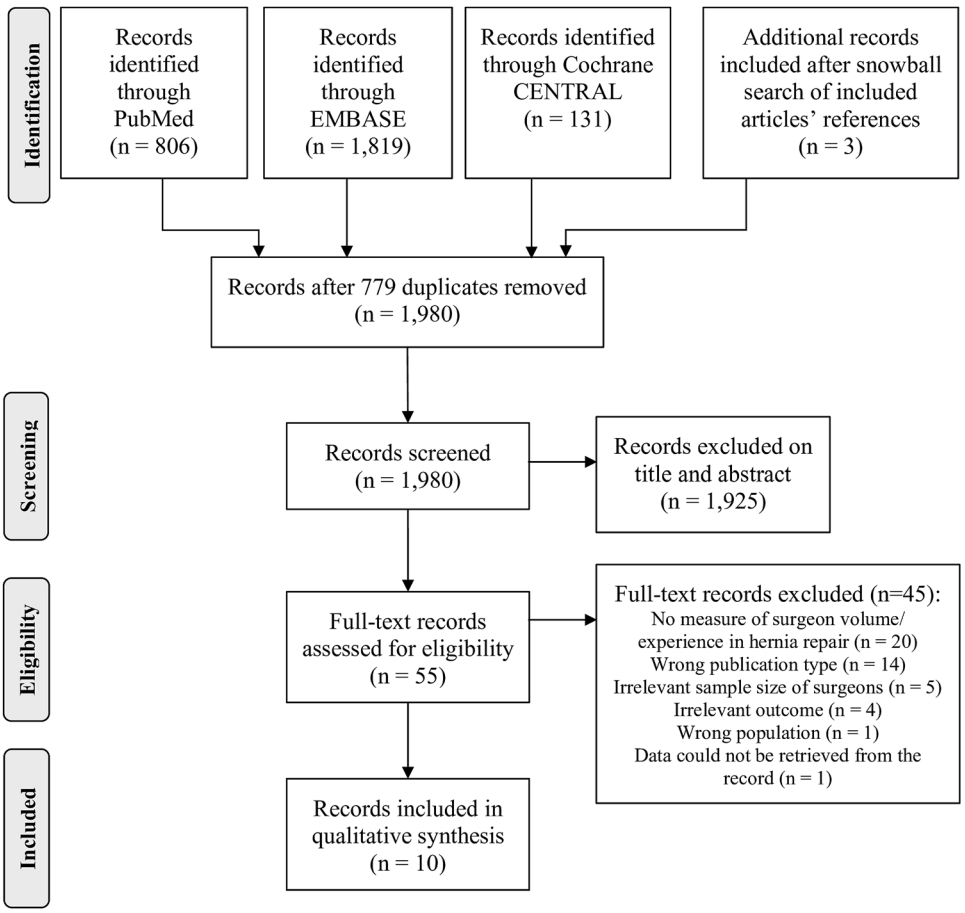

Fig. 1 PRISMA flowchart showing the study selection process

to recurrence [24, 25, 27, 28, 30, 31], patient-reported symptoms of recurrence [29], patient and surgeon reported symptoms [26], and recurrence diagnosed by a surgeon or during reoperation [22, 23]. The total number of unique patients who underwent groin hernia repair was 476,448 [22, 24, 26–29, 31]. Of the included patients, 474,465 [24, 26–29, 31] were from studies reporting on the annual surgeon volume (cases/year), and 1,983 patients [22] were from the trial reporting on total surgical experience (total number of cases). The included records had a minimum follow-up time of 12 months or a minimum median follow-up time of 42 months [29, 31]. Four of the seven studies with unique patient data specified the number of surgeons [26, 28, 29, 31], which was 3996 surgeons across these four studies. The remaining three studies with original patient data did not specify the number of groin hernia surgeons [22, 24, 27].

Annual surgeon volume

Data on recurrence or reoperation rate based on annual surgeon volume were pooled separately for five studies [26–29, 31] and are shown in Table 2. Pooled recurrence or reoperation rates were calculated for four studies [26, 28, 29, 31], while the median reoperation rate was used to pool the data from one study [27]. The recurrence rate and reoperation rate seemed to increase when annual surgeon volume decreased, giving high-volume surgeons a lower recurrence rate and low-volume surgeons a higher recurrence rate. This is depicted in Fig. 2. The increase in recurrence or reoperation rate was significant for open procedures in one study [28] and for laparoscopic procedures in three studies [26, 27, 29]. The median recurrence or reoperation rate (range) after laparoscopic repair for high-, medium-, and low-volume surgeons were 2.6% (2.3–3.0), 2.4% (0.7–4.6), and 4.2% (1.0–6.8), respectively. The median recurrence or reoperation rate (range) after open repair for high-, medium-, and low-volume surgeons were 2.1% (2.0–2.2), 1.7% (1.6–2.3), and 2.4% (2.0–2.6), respectively.

Total surgical experience

The effect of total surgical experience on recurrence rate after inguinal hernia repair was investigated in one unique study population but reported in two records [22, 23]. The recurrence rate after laparoscopic repair of primary inguinal hernia for experienced surgeons (> 250 total cases) and inexperienced surgeons (≤ 250 total cases) were 5.1% and 12.3%, respectively ($p < 0.001$). After open repair, the recurrence

Table 1 Characteristics of included records

Authors	Year	Country	Study period	Type of hernia (no. of repairs)	Type of repair (no. of repairs)	Surgeon definition		NOS risk of bias[a]
						High-volume [cases/year]	Experienced [cases]	
Randomized controlled trial								
Neumayer et al. [22, 23][b]	2004	USA	1999–2001	Inguinal (1,983)	Lap. (989) Open (994)	NR	> 250	NA
Prospective cohort studies								
Nordin et al. [24], van der Linden et al. [25][b]	2008	Sweden	1996–2004	Inguinal (94,077)	Lap. (NR) Open (NR)	> 50	NR	6
				Femoral (2,524)	Lap. (NR) Open (NR)			
Köckerling et al. [26]	2016	Germany	2009–2014	Inguinal (16,290)	TAPP (NR) TEP (NR)	≥ 25	NR	7
				Femoral (262)	TAPP (NR) TEP (NR)			
Retrospective cohort studies								
El-Dhuwaib et al. [27]	2012	UK	2002–2004	Inguinal (125,342)	Lap. (8,108) Open (117,234)	> 60	NR	6
Aquina et al. [28]	2015	USA	2001–2008	Inguinal (162,588)	Open (162,588)	≥ 25	NR	8
AlJamal et al. [29]	2016	USA	1995–2011	Inguinal (2,193) Pantaloon (174) Femoral (43)	TEP (2,410)	> 30	NR	5
Aquina et al. [30][b]	2017	USA	2003–2009	Umbilical/ epigastric (78, 267)	Lap. (10,326) Open (67, 941)	≥ 30	NR	8
Ramjist et al. [31]	2018	Canada	2003–2012	Inguinal (93,501)	Lap. (13,613) Open (79,888)	> 50	NR	7

Lap. Laparoscopic, NA not applicable, *NR* not reported, *TAPP* transabdominal preperitoneal inguinal hernia repair, *TEP* total extraperitoneal inguinal hernia repair

[a]According to Newcastle–Ottawa Scale (NOS) [21]

[b]Records with duplicate data on study population with groin hernia which are not reported in this table

rate for experienced surgeons (> 250 total cases) and inexperienced surgeons (≤ 250 total cases) were 4.1% and 2.5%, respectively ($p = 0.12$) [22]. The impact of the surgeons' age on the recurrence rate after the laparoscopic repair was also investigated in this study population [23]. The recurrence rate for experienced surgeons aged < 45 years and ≥ 45 years were 5.8% and 2.6%, while the recurrence rate for inexperienced surgeons aged < 45 years and ≥ 45 years were 3.4% and 18.3%. The differences in recurrence rate between the two age groups for both experienced and inexperienced surgeons were statistically significant (no p value reported).

Postoperative complications

Two included studies [26, 29] reported on postoperative complications in relation to annual surgeon volume after laparoscopic groin hernia repair. Postoperative complications were assessed and converted to Clavien–Dindo classification [19]. One study reported the rate of postoperative complications for Clavien–Dindo grade I–II for surgeons with < 15 cases/year and > 30 cases/year being 36% and 13%, respectively ($p < 0.0001$) [29]. Meanwhile, another study reported that for surgeons with < 25 cases/year and ≥ 25 cases/year, the rate of postoperative complications for Clavien-Dindo grade I–II were 2.2% and 5.0%, respectively ($p < 0.001$) [26]. However, this difference was mainly due to the significantly lower seroma rate in low-volume surgeons since the large hernias and scrotal hernias were mainly operated on by experienced surgeons. The study found no significant difference in postoperative complications leading to reoperation.

Operation time

Three studies [25, 28, 29] reported on the operation time for groin hernia based on annual surgeon volume, which showed that higher annual surgeon volume led to a shorter

Table 2 Pooled recurrence and reoperation rates after groin hernia repair

Type of repair Study	Outcome definition	Pooled reoperation and recurrence rate %			Follow-up, months
		High, > 50 cases/year	Medium, 11–50 cases/year	Low, ≤ 25 cases/year	
Open repair					
[28]	Reoperation	NR	1.6	2.0	60
[27]	Reoperation[a]	2.15	2.3	2.6	72
[31]	Reoperation	2.0	1.7	2.4	66[b]
Laparoscopic repair					
[29]	Recurrence	NR	1.8	4.3	42[c], 47[d], 80[e]
[26]	Recurrence	NR	0.7	1.0	12
[27]	Reoperation[a]	3.0	4.6	6.8	72
[31]	Reoperation	2.3	3.0	4.1	66[b]

Recurrence or reoperation rate after groin hernia repair of the included studies pooled into annual surgeon volume categories: high, medium, and low annual volume

NR not reported

[a]Reoperation rate pooled by calculating the median reoperation rate for the respective annual volume categories in the study

[b]Median follow-up time

[c]Median follow-up for surgeons with < 15 cases/year

[d]Median follow-up for surgeons with 15–30 cases/year

[e]Median follow-up for surgeons with > 30 cases/year

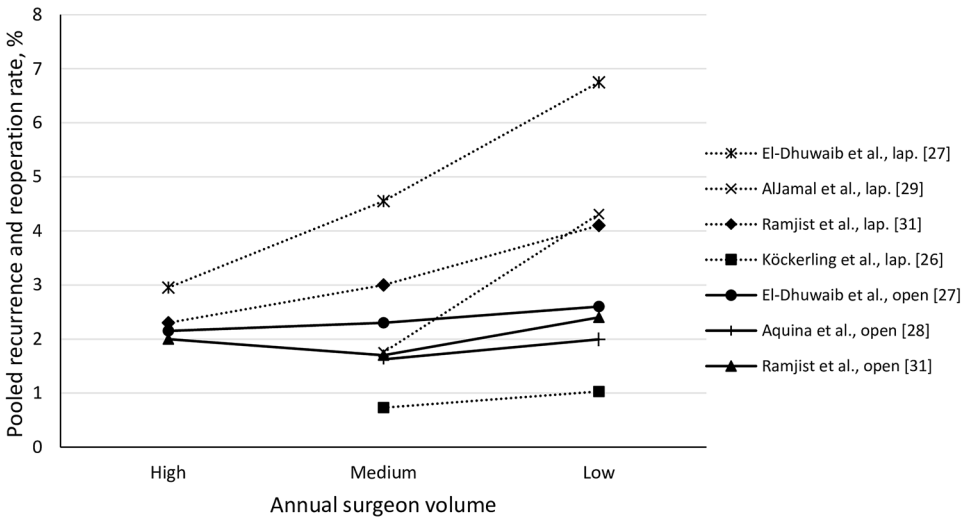

Fig. 2 Long-term recurrence or reoperation rate of groin hernia repair pooled according to annual surgeon volume. Data on laparoscopic repairs is depicted with perforated lines between data points. Data on open repair is depicted with solid lines between data points. High-volume: > 50 annual cases. Medium-volume: 11–50 annual cases. Low-volume: ≤ 25 annual cases

operation time. Annual surgeon volume of < 25 cases/year led to longer operation times while an annual surgeon volume of > 50 cases/year was associated with shorter operation time, however, the type of surgery (open or laparoscopic) was not specified [25]. For unilateral laparoscopic groin hernia repair, annual surgeon volume of < 15 cases/year was associated with longer operation time ($p = 0.008$) [29]. For open inguinal hernia repair, surgeons with an annual volume of < 25 cases/year had an average duration of the operation that was approximately 30 min longer than the annual surgeon volume of ≥ 25 cases/year [28].

No records were reported on the 30-day readmission rate and the 30-day postoperative mortality rate in relation to annual surgeon volume or total surgical experience.

Umbilical and epigastric hernia

One included study reported on umbilical and epigastric hernia [30]. This study included a total of 78,267 patients reported based on annual surgeon volume, and recurrence was defined as the reoperation rate. The total number of surgeons performing umbilical and epigastric hernia repairs

was 2012 [30]. The characteristics of this study are shown in Table 1.

Annual surgeon volume of > 30 cases/year was associated with a lower reoperation rate of 7.7%, while annual surgeon volume of < 20 cases/year was associated with a greater reoperation rate of 10.3% ($p < 0.0001$) [30].

Discussion

This systematic review included ten records, of which seven had unique patient data on groin hernia repair, and one had unique patient data on umbilical and epigastric hernia repair. For groin hernia repair, the median recurrence or reoperation rate seemed to increase when annual surgeon volume decreased below 25 cases/year. Furthermore, increased annual surgeon volume was in three studies found to be associated with decreased operation time. The study on umbilical and epigastric hernia repair found that annual surgeon volume above 30 was associated with a significantly lower reoperation rate.

This systematic review has several strengths. The systematic search strategy was developed in cooperation with a research librarian, and a snowball search was conducted with the aim of identifying all relevant literature on the subject. This review followed the PRISMA guideline [16], ensuring transparency of the review's reporting. Furthermore, a predefined protocol was uploaded to PROSPERO [17] prior to data extraction, minimizing the risk of reporting bias and allowing comparison of predefined and reported items in the review. The screening of records and the risk of bias assessment were conducted independently and in parallel by two reviewers and discrepancies were resolved within the author group. Only data on unique study populations were reported in this review and overlapping data from included records were omitted. However, there were also limitations to this systematic review. Only records that reported on annual surgeon volume or total surgical experience were considered for inclusion. Records only reporting recurrence based on surgeons' level of training or surgeons' postgraduate year were excluded, as were records reporting on the caseload needed to overcome the learning curve for specific procedures. Records reporting on the surgical learning curve generally reported higher recurrence rates at the beginning of the learning curve, which dropped as the learning curve was achieved [33–35]. Although of relevance, this information did not allow us to follow the continuous relation between annual surgeon volume or total surgical experience and the long-term outcome after hernia repair. Limiting the included records to outcome based on annual surgeon volume or total surgical experience allowed for a somewhat uniform measurement, enabling us to assess the annual volume-outcome relation for surgeons, which was useful when assessing the surgical quality [36]. There was a risk of underestimating the actual recurrence rate in records reporting the reoperation rate [24, 27, 28, 30, 31], since not all recurrent groin, umbilical and epigastric hernias are reoperated [3, 4]. Furthermore, the records reporting recurrence rates based on patient or consultant reported symptoms [26, 29] perhaps underestimated the actual recurrence rate, since only symptomatic recurrent hernia were reported. The cut-off values and definitions for annual surgeon volume in the included studies varied as did the definition of high-volume surgeons, varying from > 60 cases/year [27] to ≥ 25 cases/year [26, 28]. This made it difficult to generate a clear cut-off value for annual surgeon volume across the included studies, leading to an overlap between the low and medium-volume categories in this review. To ensure standardized cut-off values for annual surgeon volume, future studies should include at least two cut-off values for annual surgeon volume, i.e. at ≤ 25 cases/year and at > 50 cases/year. The sole included randomized controlled trial [22] reported a high recurrence rate after laparoscopic inguinal hernia repair based on total surgical experience with an overall recurrence rate of 10% after two years. The high recurrence rate might have been due to the application of different and too small mesh sizes in the trial [32], leading to a high risk of bias assessment of the trial. The mean vertical dimension of the used meshes was smaller for patients with recurrence compared with patients without recurrence in the trial (8.1 ± 0.6 cm vs. 8.5 ± 1.3 cm, $p < 0.001$) [32]. For laparoscopic hernia repair the mesh size should be at least 10×15 cm [37] since smaller mesh sizes have been associated with a higher recurrence rate after groin hernia repair [38]. Thus, the high recurrence rate after laparoscopic inguinal hernia repair could not be explained solely by total surgical experience or lack thereof since it was most probably affected by the applied mesh size.

In conclusion, a higher annual surgeon volume was associated with a significantly lower recurrence rate and reoperation rate after groin hernia repair. The available data suggest that the individual surgeon should perform at least 25 groin hernia repairs per year. The definition of high-volume surgeons varied across the included records, and future studies should include standardized cut-off values for annual surgeon volume at ≤ 25 cases/year and > 50 cases/year and, additionally, maybe higher cut-off values can be included. After umbilical and epigastric repair, the available data also suggest a beneficial effect of increased annual surgeon volume on the long-term outcome suggesting that the individual surgeon should perform at least 30 repairs annually. However, only one included study reported on umbilical and epigastric hernia and the reoperation rate based on annual surgeon volume, and there are implications for further research on this subject. Overall, the data found in this review seem to support the centralization of groin hernia repair on individual surgeons to ensure a better long-term outcome.

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Data availability Data can be obtained from the corresponding author by e-mail.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval Not applicable.

Human and animal rights Not applicable.

Informed consent Not applicable.

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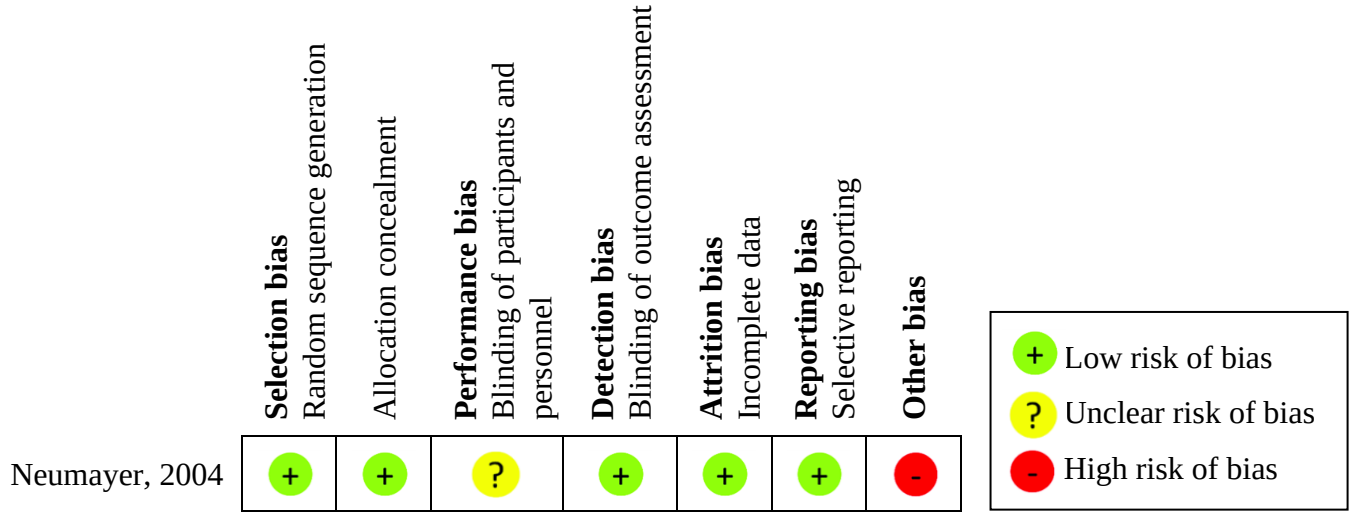
Supplementary Material 1 Risk of bias assessment of the included randomized controlled trial, using Cochrane Risk of Bias tool



Lower recurrence rate after groin and primary ventral hernia repair performed by high-volume surgeons: a systematic review. Hernia. Christophersen C, Fonnes S, Andresen K, Rosenberg J. Corresponding author: Christophersen.camilla@gmail.com

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ORIGINAL ARTICLE

Lower reoperation rates after open and laparoscopic groin hernia repair when performed by high-volume surgeons: a nationwide register-based study

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Abstract

Purpose Previous studies have shown a correlation between surgeons with high annual volume and better outcomes after various surgical procedures. However, the preexisting literature regarding groin hernia repair and annual surgeon volume is limited. The aim was to investigate how annual surgeon volume affected the reoperation rates for recurrence after primary groin hernia repair.

Methods This nationwide cohort study was based on data from the Danish Hernia Database and the Danish Patient Safety Authority's Online Register. Patients ≥ 18 years undergoing laparoscopic or Lichtenstein primary groin hernia repair between November 2011 and January 2020 were included. Annual surgeon volume was divided into five categories: ≤ 10, 11–25, 26–50, 51–100, and > 100 cases/year.

Results We included 25,262 groin hernia repairs performed in 23,088 patients. The risk of reoperation for recurrence after Lichtenstein repair was significantly higher for the volume categories of ≤ 10 (HR 4.02), 11–25 (HR 3.64), 26–50 (HR 3.93), or 51–100 (HR 4.30), compared with the > 100 category. The risk of reoperation for recurrence after laparoscopic repair was significantly increased for the volume categories of ≤ 10 (HR 1.89), 11–25 (HR 2.08), 26–50 (HR 1.80), and 51–100 (HR 1.58) compared with the > 100 category.

Conclusion The risk of reoperation for recurrence was significantly higher after Lichtenstein and laparoscopic repairs performed by surgeons with < 100 cases/year compared with > 100 cases/year. This indicates that higher surgeon volume minimizes the risk of reoperation for recurrence after groin hernia repair.

Keywords Groin hernia · Inguinal hernia · Reoperation · Annual surgeon volume

Introduction

Groin hernia repair is a common surgical procedure worldwide and approximately 27% of men and 3% of women will undergo groin hernia repair at some point in their life [1]. Surgical experience is often assessed by the surgeons' volume of procedures [2]. A relation between high annual surgeon volume and a better outcome of surgical procedures has previously been suggested e.g. in bariatric surgery [3, 4], cholecystectomy [5], liver resection [6], colorectal surgery [7], and pancreaticoduodenectomy [8]. High-volume centers have a lower risk of reoperation after inguinal hernia repair compared with low-volume centers [9]. However, hospital volume cannot be used as a direct parallel to surgeon volume [10], thus, it is relevant to investigate the effect of surgeon volume on the recurrence related reoperation rate after hernia repair. A recent retrospective study found a lower recurrence related reoperation rate after inguinal hernia repair when performed by high-volume compared with low-volume surgeons [11]. In order to improve outcomes, centralization of surgery has been debated. The impact of annual surgeon volume on the recurrence related reoperation rate after groin hernia repair has not previously been investigated in a nationwide cohort including both private and public health care providers.

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This study aimed to investigate how the annual surgeon volume affects the reoperation rate for recurrence after primary inguinal and femoral hernia repair in a nationwide cohort.

Methods

This register-based cohort study based on prospectively collected data of nationwide groin hernia repairs was reported according to the REporting of studies Conducted using Observational Routine-collected health Data (RECORD) statement [12]. Data were obtained from the Danish Hernia Database, which was established in 1998 [13]. The database includes > 90% of groin hernia repairs performed in Denmark, and it is mandatory for both public and private healthcare providers to register data in the database. The Danish Hernia Database contains data on surgeons' authorization ID that became a required field in 2016. However, authorizations IDs were possible to enter already from 2011. The Danish Hernia Database also contains general data such as patients' sex, age, date of surgery, and whether the repair was elective or acute. Furthermore, the database provides data on hernia characteristics such as side, size according to the European Hernia Society (EHS) classification [14], whether the hernia was primary or recurrent, type of hernia, method of repair, and the method of anesthesia. The Danish Hernia Database is linked to the Danish National Patient Register [15]. A unique civil personal register number is used for all contacts to both public and private hospitals [15]. Thus, a reoperation will be registered in the Danish National Patient Register, even if it is not registered in the Danish Hernia Database. In addition, the Danish Hernia Database also draws information from the Danish Civil Registration System [16] which made it possible to identify patients who emigrated from Denmark or died, including the date of death. Data on the surgeons were obtained from the publicly available Danish Patient Safety Authority's Online Register [17]. This register holds information on all authorized health professionals in Denmark through a unique authorization ID. Data on the included surgeons were anonymized before the analyses. The Danish Patient Safety Authority's Online Register also includes data such as authorization validity, surgeon's date of birth, the date of authorization, the surgeon's field of specialization, and the date of approved specialization. The unique surgeon authorization IDs were used to link data from the Danish Hernia Database with the data from the Danish Patient Safety Authority's Online Register.

Patients were operated on between November 1, 2011, and January 1, 2020. Patients were followed until recurrence, death, or the date of data extraction (January 1, 2020). Reoperation for recurrence was defined as subsequent hernia repair on the same side. Data on reoperation was obtained from the Danish Hernia Database and the Danish National Patient Register.

Eligibility criteria for groin hernia repairs were repairs performed in patients ≥ 18 years undergoing emergency or elective repair for primary groin hernia and using laparoscopic or open Lichtenstein technique. Groin hernia repairs registered as reoperation for recurrence on the first entry in the database were excluded. Furthermore, a "look back" was conducted from 1998 to 2011 to identify patients who had had a previous groin hernia repair on the same side, which also led to exclusion. The majority of laparoscopic groin hernia repairs in Denmark are TransAbdominal PrePeritoneal (TAPP) repairs. Total ExtraPeritoneal (TEP) laparoscopic repair accounted for < 2% of the groin hernia repairs in the Danish Hernia Database [9] and therefore TEP was not accounted for in the analyses. The exclusion criteria for groin hernia repairs were: no registration of hernia type, recurrent hernia, patients who had emigrated or taking residence outside of Denmark, no registered surgeon authorization ID, and invalid surgeon authorization ID. Furthermore, authorization IDs were excluded if a single authorization ID was registered ≤ 2 times during the entire study period.

Our primary outcome was recurrence related reoperation rate for the different annual surgeon volume categories. The secondary outcomes were: recurrence related reoperation rate in relation to surgeons' age which was dichotomized into < 45 and ≥ 45 years, the number of years since the surgeon's medical graduation, and years since the surgeon's specialization. Annual surgeon volume was reported separately for Lichtenstein and laparoscopic TAPP repairs and grouped into five categories: ≤ 10, 11–25, 26–50, 51–100, and > 100 cases/year, based on the volume categories previously used in the literature [18]. The annual surgeon volume was determined as the number of repairs performed by the individual surgeon in the 12 months before the index operation. Thus, annual surgeon volume was calculated as a dynamic variable, allowing surgeons to change annual volume category throughout the study period. The number of repairs from the first calendar year was used to determine the annual surgeon volume in the individual surgeons' first year in the study period. We conducted a sensitivity analysis, where the repairs from the first calendar year were excluded from the analysis. The individual surgeon could change volume categories, and data on the individual surgeon were presented for the category in which the surgeon performed most of their repairs. The subgroup analyses were conducted of the adjusted recurrence-related reoperation rate for elective repairs based on annual surgeon volume.

Statistical analyses were performed in SPSS (version 25.0, IBM, Armonk, NY, USA). Q-Q-plots and histograms were used to assess if data were normally distributed. The median time to follow-up was presented with interquartile range [IQR]. The Chi-squared test was used to compare

categorical data such as crude reoperation rates. The main analyses were conducted with Cox Proportional Hazard Analyses for reoperation reported by annual surgeon volume and presented as hazard ratios (HR) with 95% confidence intervals (CI). The Cox Proportional Hazard Analyses were adjusted for patients' age, sex, hernia type, and hernia defect size. Furthermore, the analyses were adjusted for the method of anesthesia in the Lichtenstein cohort. To assess the cumulative reoperation rate, we performed a Kaplan–Meier plot for both the Lichtenstein and laparoscopic cohort.

This study was approved by the Danish Data Protection Agency (P-2020-380). Approval from ethics committees and informed written consent from patients were not required for this specific type of study according to Danish law.

Results

We included 25,260 groin hernias in 23,088 patients. The study population selection process is depicted in the flowchart in Fig. 1. We included a total of 561 surgeons, where 546 surgeons performed Lichtenstein repairs and 331 surgeons performed laparoscopic TAPP repairs. There were 9,898 repairs performed in 9,845 patients in the Lichtenstein cohort, and 15,362 groin hernia repairs performed in 13,243 patients in the laparoscopic TAPP cohort. The patient demographics and operative characteristics are presented in Tables 1 and 2 for the Lichtenstein and laparoscopic TAPP cohort, respectively.

Figure 2 shows the crude recurrence-related reoperation rate in the Lichtenstein and laparoscopic TAPP cohort reported based on annual surgeon volume. The overall crude reoperation rate was 253 (2.6%) and 395 (2.2%) in the Lichtenstein and the laparoscopic TAPP cohort, respectively. In the Lichtenstein cohort, there seemed to be an increased

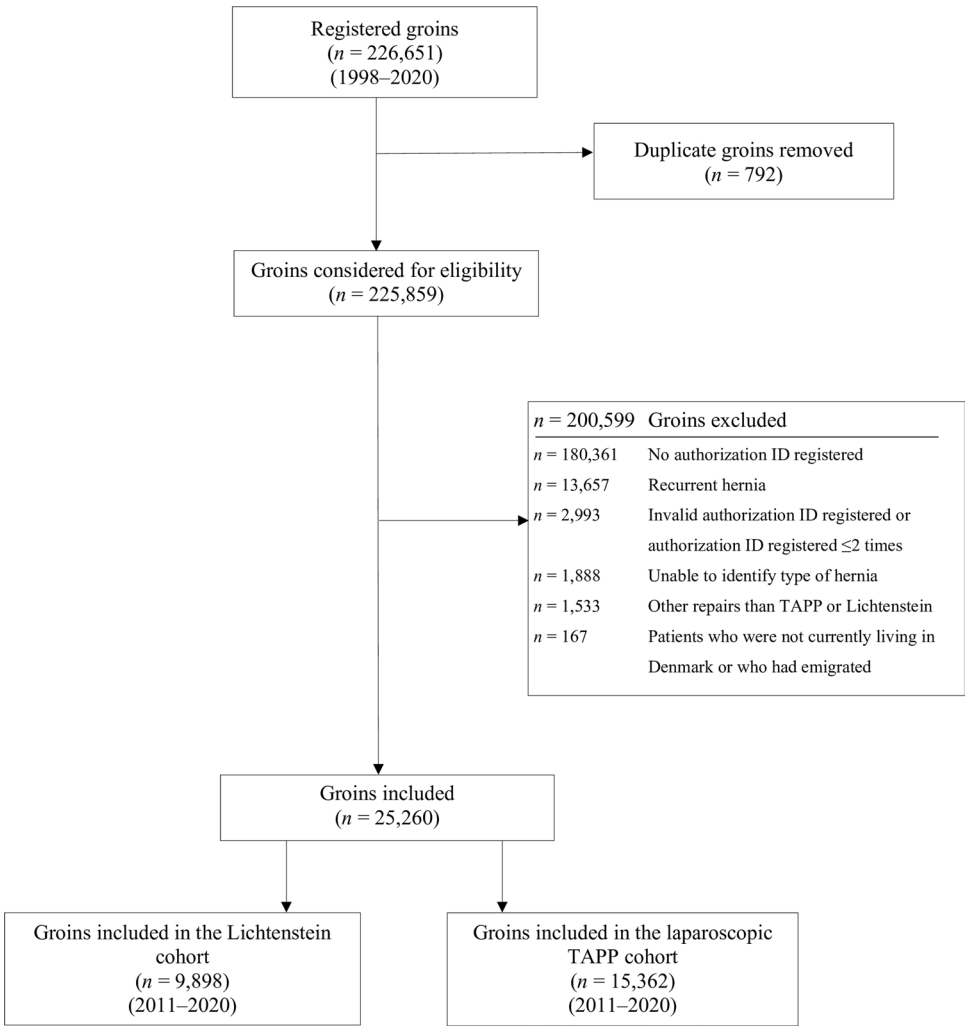

Fig. 1 Flowchart of inclusion of groins. *TAPP* transabdominal preperitoneal laparoscopic repair

Table 1 Patient demographics and operative characteristics for the Lichtenstein cohort according to annual surgeon volume

		Annual surgeon volume (cases/year)				
	Total $n=9898$ (100)	≤10 $n=3619$ (37)	≤10 $n=3619$ (37)	26–50 $n=1841$ (19)	26–50 $n=1841$ (19)	>100 $n=532$ (5)
Age, years	68 [58–74]	69 [59–75]	68 [58–75]	67 [57–73]	64 [52–72]	67 [55–73]
Sex, male	9735 (98)	3537 (98)	3328 (99)	1819 (99)	526 (99)	525 (98)
Defect size						
EHS 1	806 (8)	265 (8)	286 (9)	169 (9)	35 (7)	51 (10)
EHS 2	5831 (61)	2081 (62)	2038 (62)	1135 (62)	272 (51)	305 (57)
EHS 3	2913 (31)	1039 (31)	941 (29)	531 (29)	226 (42)	176 (33)
Type of hernia						
Inguinal						
Lateral	5748 (58)	2079 (58)	1900 (56)	1076 (58)	351 (66)	342 (64)
Medial	3255 (33)	1175 (33)	1132 (34)	610 (33)	170 (32)	168 (32)
Pantaloon	868 (9)	353 (10)	331 (10)	149 (8)	13 (2)	22 (4)
Combined	27 (0.3)	12 (0.3)	9 (0.3)	6 (0.3)	0	0
Emergency repair	500 (5)	349 (10)	121 (4)	27 (2)	3 (1)	0
Method of anesthesia						
General	7569 (77)	3010 (83)	2442 (72)	1252 (68)	334 (63)	531 (99.8)
Local	2216 (22)	566 (16)	888 (26)	565 (31)	197 (37)	0
Spinal	113 (1)	43 (1)	42 (1)	24 (2)	3 (0.6)	1 (0.2)
Reoperation	253 (3)	92 (3)	83 (3)	54 (3)	21 (4)	3 (1)
Follow-up, months	24 [13–34]	21 [11–32]	24 [13–34]	25 [16–36]	34 [26–38]	19 [11–31]

Data are presented as median [interquartile range] or number (%)

EHS European Hernia Society

Table 2 Patient demographics and operative characteristics for the laparoscopic TAPP cohort according to annual surgeon volume

	Annual surgeon volume (cases/year)					
	Total $n=15{,}362$ (100)	≤10 $n=2379$ (15)	11–25 $n=2365$ (15)	26–50 $n=2898$ (19)	51–100 $n=3931$ (26)	>100 $n=3789$ (25)
Age, years	58 [47–69]	61 [49–72]	60 [48–70]	59 [47–69]	58 [47–69]	57 [47–67]
Sex, male	12,783 (83)	1798 (76)	1846 (78)	2383 (82)	3327 (85)	3429 (91)
Defect size						
EHS 1	2005 (13)	401 (18)	425 (19)	452 (16)	544 (14)	183 (5)
EHS 2	10,228 (68)	1522 (67)	1449 (64)	1857 (65)	2512 (64)	2888 (76)
EHS 3	2870 (19)	350 (15)	407 (19)	547 (19)	851 (22)	715 (19)
Type of hernia						
Inguinal						
Lateral	8369 (55)	1121 (51)	1270 (54)	1607 (56)	2141 (55)	2130 (56)
Medial	5089 (33)	803 (34)	750 (32)	912 (32)	1301 (33)	1323 (35)
Pantaloon	779 (5)	123 (5)	132 (6)	139 (5)	214 (5)	171 (5)
Femoral	818 (5)	182 (8)	161 (7)	187 (7)	194 (5)	94 (3)
Combined	307 (2)	50 (2)	52 (2)	53 (2)	81 (2)	71 (2)
Emergency repair	510 (3)	164 (7)	117 (5)	109 (4)	103 (3)	17 (0.4)
Reoperation	335 (2)	66 (3)	65 (3)	69 (2)	85 (2)	50 (1)
Follow-up, months	22 [11–33]	27 [14–38]	25 [12–37]	23 [11–34]	21 [11–31]	20 [10–29]

Data are presented as median [interquartile range] or number (%)

TAPP transabdominal preperitoneal laparoscopic repair, *EHS* European Hernia Society

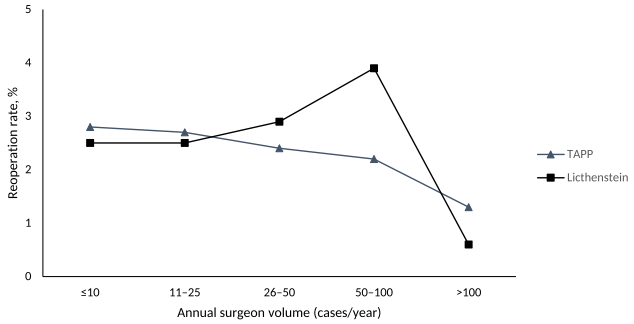

Fig. 2 Crude reoperation rate and annual surgeon volume. *TAPP* transabdominal preperitoneal laparoscopic repair

crude reoperation rate in the 26–50 (3.9%) and 51–100 (3.9%) volume categories compared with annual surgeon volume of > 100 cases/year (0.6%) (Table 1 and Fig. 2). In the laparoscopic cohort, there was a decreasing recurrence related reoperation rate when annual surgeon volume surpassed > 100 cases/year (1.3%), while the crude reoperation rates were higher when performed by surgeons in volume categories of ≤ 10 (2.8%), 11–25 (2.7%), 26–50 (2.4%), and 51–100 (2.2%) (Table 2 and Fig. 2). The median [IQR] time to follow up was 24 [13–34] and 22 [11–33] months for the Lichtenstein and the laparoscopic TAPP cohort, respectively. Characteristics of the included surgeons are presented in Table 3 for all volume categories including > 5 surgeons.

In the Lichtenstein cohort, the HR for recurrence-related reoperation for each annual surgeon volume category was adjusted for patients' sex, age, type of hernia, defect size, and method of anesthesia. The reference category was the > 100 volume category, and the HRs for the Lichtenstein cohort are shown in Table 4. The low-volume categories ≤ 10 (HR 4.02), 11–25 (HR 3.64), 26–50 (HR 3.93), and 51–100 (HR 4.30) cases/year all had a significantly higher risk of reoperation for recurrence compared with the > 100 category. Figure 3a depicts the cumulative risk of reoperation for each annual surgeon volume category.

In the laparoscopic TAPP cohort, the HR for recurrence-related reoperation for each annual surgeon volume category was adjusted for patients' age, sex, hernia type, and hernia defect size. The reference category was the > 100 volume category, and the HRs for the laparoscopic TAPP cohort is shown in Table 4. The volume categories ≤ 10 (HR 1.89), 11–25 (HR 2.08), 26–50 (HR 1.80), and 51–100 (HR 1.58) cases/year all had a significantly higher risk of reoperation for recurrence compared with the > 100 category. The analyses for the Lichtenstein and the laparoscopic TAPP cohort

Table 3 Surgeon characteristics of the 576 included surgeons

	Total	Annual surgeon volume (cases/year)				
		≤ 10	11–25	26–50	51–100[a]	> 100[a]
Lichtenstein surgeons						
Number of surgeons	546	388	121	32		
Age, years	38 [33–48]	38 [33–46.5]	37 [31–48]	40 [34–58.5]		
< 45	378 (69)	281 (72)	79 (65)	18 (56)		
≥ 45	168 (32)	107 (28)	42 (35)	14 (34)		
Years since						
Graduation	9 [3–16]	9 [4–15]	7 [3–18]	9 [4–28]		
Specialization	7 [2–14]	5 [1–11]	11 [5–15]	14 [7–20]		
Surgeons currently not specialized	278 (51)	193 (50)	69 (57)	15 (47)		
Laparoscopic TAPP surgeons						
Number of surgeons	331	210	50	34	28	9
Age, years	40 [34–50]	37 [33–44]	40 [36–47]	48 [44–57]	51.5 [43–63.5]	56 [51–62]
< 45	211 (64)	158 (75)	34 (68)	11 (32)	8 (29)	0
≥ 45	120 (36)	52 (25)	16 (32)	23 (68)	20 (71)	9 (100)
Years since						
Graduation	10 [6–19]	8 [4–14]	11 [7–18]	17 [11–29]	22 [13–33]	26 [21–35]
Specialization	6 [1–12.5]	4 [0–11]	4 [1–11]	7.5 [2.5–15]	9 [2–16]	11 [10–16]
Surgeons currently not specialized	131 (40)	111 (53)	16 (32)	2 (6)	2 (7)	0

The individual surgeon was able to change volume categories and data on the individual surgeon are presented for the category in which the surgeon performed most of their repairs. Data are presented as median [interquatile range] or number (%)

TAPP transabdominal preperitoneal laparoscopic repair

[a]Not reported for the Lichtenstein cohort, since the total number of surgeons in each category was too low to ensure that the data on these surgeons were anonymized

Table 4 Results of the Cox Proportional Hazard Analyses for the Lichtenstein and the laparoscopic TAPP cohort with the risk of reoperation for recurrence

	Hazard ratio	95% CI	*P* value
Lichtenstein repair			
Annual surgeon volume, (cases/year)			
≤ 10	4.02	1.27–12.75	0.018
11–25	3.64	1.15–11.58	0.028
26–50	3.93	1.22–12.64	0.022
51–100	4.30	1.27–14.54	0.019
> 100	1		
Laparoscopic TAPP repair			
Annual surgeon volume, (cases/year)			
≤ 10	1.89	1.29–2.77	0.001
11–25	2.08	1.43–3.01	< .0001
26–50	1.80	1.25–2.59	0.002
51–100	1.58	1.11–2.24	0.010
> 100	1		

The hazard ratio for Lichtenstein repair was adjusted for patients' age, sex, the type of hernia, size of the defect according to European Hernia Society (EHS), and the method of anesthesia. The hazard ratio for laparoscopic TAPP repair was adjusted for patients' age, sex, the type of hernia, and size of the defect according to EHS

CI confidence interval, *TAPP* transabdominal preperitoneal laparoscopic repair

with the adjusted covariates are shown in Supplementary Material 1. The cumulative risk of reoperation for the laparoscopic TAPP cohort is shown in Fig. 3b for each annual surgeon volume category.

In the sensitivity analyses, the repairs performed during the first year were excluded. The sensitivity analyses included 5,170 (52%) and 10,578 (69%) groin hernia repairs of the total Lichtenstein and laparoscopic TAPP cohort, respectively. The sensitivity analyses showed an increased HR for the ≤ 10, 11–25, 26–50, and 51–100 volume categories compared with the > 100 volume category for both the Lichtenstein and the laparoscopic TAPP cohort. The increased HR was significant in the 26–50 and 51–100 volume categories for the Lichtenstein cohort, and the increased HR was significant for the 26–50 volume category in the laparoscopic TAPP cohort (analyses not shown).

The subgroup analyses of groin hernia repairs performed electively showed similar significant findings for HR of reoperation for recurrence in the different volume categories, for both the Lichtenstein and the laparoscopic TAPP cohort (analyses not shown).

We performed three additional analyses. Firstly, we performed an analysis of groin hernia repairs performed by surgeons aged < 45 and ≥ 45 years. The analysis found no difference in the overall crude recurrence-related reoperation rate between surgeons of < 45 (2.6%) and ≥ 45 (2.4%) years after Lichtenstein repair ($p = 0.526$). After laparoscopic TAPP repair, there was also no difference between the overall crude reoperation rate for surgeons aged < 45 (1.9%) and ≥ 45 (2.3%) years ($p = 0.075$).

Secondly, an analysis was performed on the risk of recurrence-related reoperation in relation to the number of years since the surgeons' medical graduation which were adjusted for the same covariates as the primary analyses. For the Lichtenstein cohort, we found a significantly lower risk of reoperation when the years since the surgeons' graduation increased ($p = 0.024$). For the laparoscopic TAPP cohort, the number of years since surgeons' graduation did not affect the risk of reoperation ($p = 0.667$) (analyses not shown).

Thirdly, we performed an analysis on the risk of recurrence-related reoperation in relation to the number of years since the surgeons' specialization. This analysis was adjusted for the same covariates as the primary analyses. The number of years since the surgeons' specialization did not affect the risk of reoperation after Lichtenstein ($p = 0.074$) or laparoscopic TAPP repair ($p = 0.709$) (analyses not shown).

Discussion

This nationwide, register-based study found a significantly higher risk of recurrence-related reoperation amongst low and medium-volume surgeons compared with high-volume surgeons in both the Lichtenstein and the laparoscopic TAPP cohorts. Annual surgeon volume of > 100 cases/year was associated with a significantly decreased risk of reoperation compared with the lower volume categories.

In the Lichtenstein cohort, there was a significantly higher risk of reoperation for recurrence in the low-volume categories ≤ 10 and 11–25 cases/year and in the medium-volume category 26–50 cases/year compared with the > 100 volume category. Furthermore, we found a significantly higher risk of reoperation in the 51–100 volume category compared with the > 100 volume category. Surgeons in the 51–100 volume category seemed to operate more hernias classified as EHS 3 than the other volume categories, perhaps reflecting that the 51–100 volume category performed more complex hernia repairs than the low volume categories in this cohort. The risk of reoperation after Lichtenstein repair was adjusted for the method of anesthesia since local anesthesia has been associated with a higher risk of reoperation compared with regional anesthesia after primary groin hernia repair [19].

A recent large retrospective study from 2018 found a lower unadjusted crude recurrence-related reoperation rate after open groin hernia repairs performed by the medium-volume category of 26–50 cases/year than the low-volume category of ≤ 25 cases/year [11]. However, they found a small increase in the crude unadjusted reoperation rate for surgeons in the high-volume category of > 50 cases/

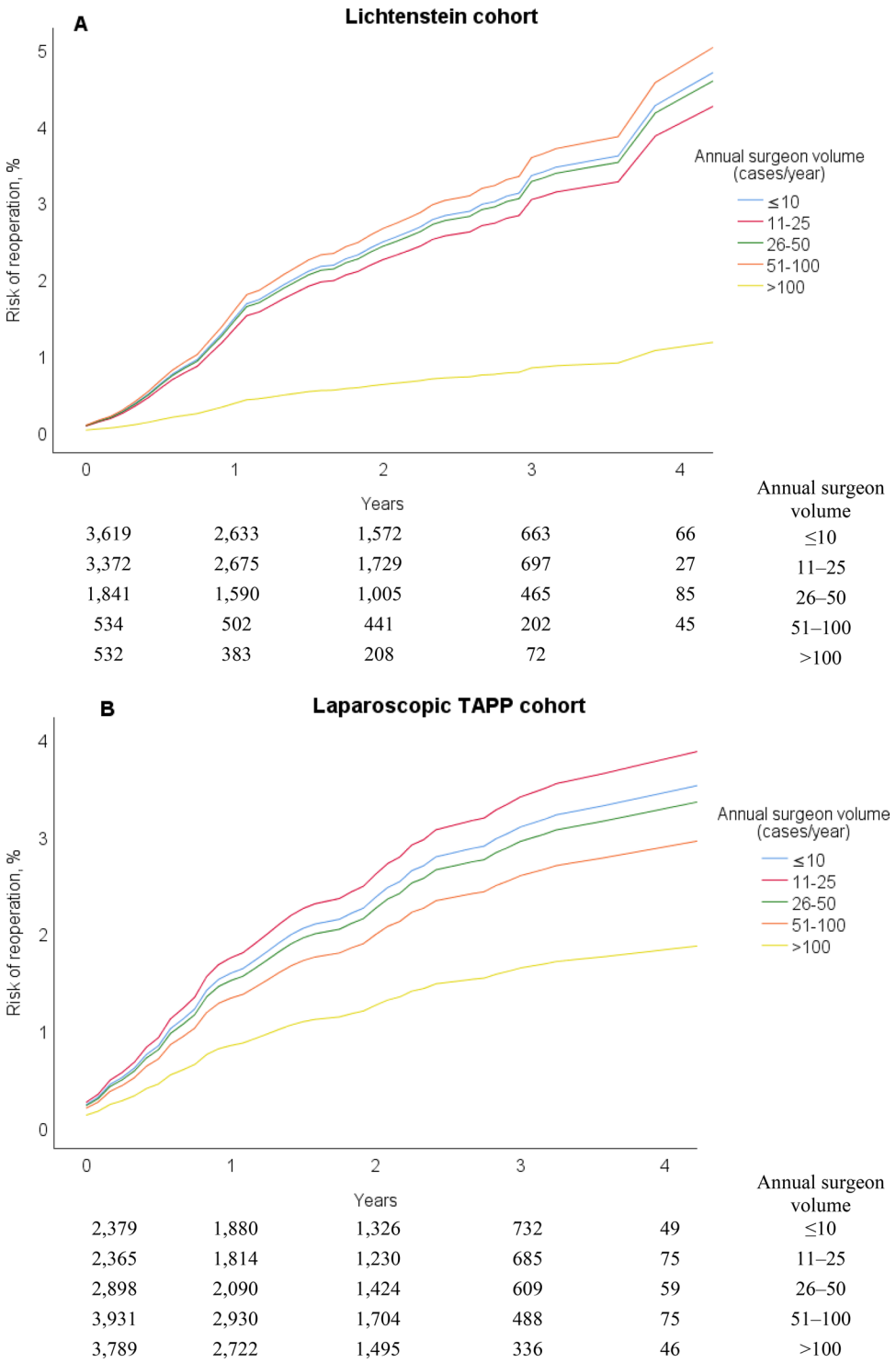

Fig. 3 **a** Kaplan–Meier plot showing cumulative reoperation rates after Lichtenstein repair of groin hernia distributed on annual surgeon volume ($p = 0.089$) with the number at risk. Adjusted for patients' age, sex, the type of hernia, size of the defect according to European Hernia Society (EHS), and the method of anesthesia. **b** Kaplan–Meier plot showing cumulative reoperation rates after laparoscopic TransAbdominal PrePeritoneal (TAPP) repair of groin hernia distributed on annual surgeon volume ($p = 0.008$) with the number at risk. Adjusted for patients' age, sex, the type of hernia, and size of the defect according to EHS

year than in the medium-volume category of 26–50 cases/year [11]. Similarly, we observed an increased HR and crude recurrence-related reoperation rate in the 51–100 medium-volume category in the Lichtenstein cohort. Furthermore, a previous study showed an increased crude reoperation rate after open groin hernia repair performed by low-volume surgeons [20], supporting the findings in the present study. Annual surgeon volume is an often used measure of surgeons' experience [2]. Hospital volume can be used as an indirect measurement of surgeons' experience; however, this is not an isolated measure as hospital volume reflects the capability and experience of the entire personnel involved in the treatment, from patients' admission to discharge [10]. Thus, annual surgeon volume

provides a more direct measure of the individual surgeon's experience.

In the laparoscopic TAPP cohort, there was a significantly increased risk of reoperation for recurrence amongst all volume categories compared with > 100 volume category. This pattern has similarly been found in previous studies where laparoscopic groin hernia repairs performed by low-volume surgeons have an increased crude recurrence-related reoperation rate compared with high-volume surgeons [11, 21–23]. Other surgeon-related factors could affect the risk of reoperation such as the supervision and training of surgeons. The increased risk of reoperation amongst lower volume surgeons compared with high-volume surgeons could perhaps indicate a need for supervision of lower-volume surgeons.

Surgeons' age dichotomized into < 45 and ≥ 45 years has previously been investigated and one study published in 2005 showed an increased mean recurrence rate after open and laparoscopic repair performed by surgeons aged ≥ 45 years [24]. However, our analyses from more recent data of surgeons' age dichotomized into < 45 and ≥ 45 years showed no significant difference in the risk of reoperation for recurrence in relation to the surgeons' age. We found a decreased risk of reoperation as the number of years since the surgeons' medical graduation increased for Lichtenstein repair, thus reflecting that the risk of reoperation is more sensitive to the actual experience of the surgeon rather than their age.

This study has several strengths. The Danish Hernia Database [13] and the Danish Patient Safety Authority's Online Register [17] both have nationwide coverage and more than 90% of groin hernia repairs performed in Denmark [13] were assessed for eligibility. The surgeon's authorization ID must be entered when registering groin hernia repairs in the Danish Hernia Database. This limited selection bias amongst the included surgeons since all groin hernia repairs performed in the study period were registered with a surgeon authorization ID. The follow-up in the Danish Hernia Database is approximately 100%, since the Danish Hernia Database also draws data from the Danish National Patient Registry [13], and therefore no patients were lost to follow-up. Furthermore, the annual surgeon volume was adjusted continuously and assessed as a dynamic variable, allowing surgeons to change the volume category throughout the study. However, there were also limitations to this study. The study size and study period were limited by the registration of surgeon authorization IDs which was needed to calculate the annual surgeon volume. A previous study has shown that the clinical recurrence rate exceeds the actual reoperation rate with approximately 40% [25]. This most likely affected the follow-up of the present study since the Danish Hernia Database only holds data on reoperation while clinical recurrences are not registered in the database. In the sensitivity analysis where data from the first year were excluded, the increased risk of reoperation for recurrence only remained significant in the 26–50 and 51–100 volume categories in the Lichtenstein cohort, and in the 26–50 volume category in the laparoscopic TAPP cohort. However, the sensitivity analysis included fewer observations than the primary analysis (52–69% of the total cohorts), and there was therefore a risk of type 2 error. Our study period was limited by when the surgeon authorization ID was registered in the Danish Hernia Database, which led to a relatively short effective study period of three years (2016–2019). However, our data contained some surgeon authorization ID registrations from 2011.

In conclusion, the findings in this study showed a higher risk of recurrence-related reoperation after repairs performed by both low- and medium-volume surgeons compared with high-volume surgeons in both the Lichtenstein and the laparoscopic TAPP cohort. There are implications for further research investigating how annual surgeon volume affects the quality of groin hernia repair, to explore the need for concentration of groin hernia surgery on fewer surgeons. Furthermore, there are logistic factors impacting the feasibility of groin hernia repair centralization such as geographics, surgical education, and training.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10029-021-02400-0.

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Data availability Anonymized data not available in the article can be provided by the corresponding author via e-mail.

Code availability Syntax code for SPSS (version 25.0, IBM, Armonk, NY, USA) can be provided by the corresponding author via e-mail.

Declarations

Conflict of interest The authors Christophersen C, Baker JJ, Fonnes S, Andresen K, and Rosenberg J declare that they have no conflicts of interest.

Ethical approval This study was approved by the Danish Data Protection Agency (P-2020–380).

Human and animal rights Not applicable.

Informed consent Not required, according to Danish law.

Consent for publication Not required, according to Danish law.

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Supplementary Material 1. Cox Proportional Hazard Analyses for the risk of reoperation for recurrence in the Lichtenstein and the laparoscopic TAPP cohort with the adjusted covariates. CI: confidence interval. TAPP: TransAbdominal PrePeritoneal laparoscopic repair. EHS: European Hernia Society.

	Hazard ratio	95% CI	*P* value
Lichtenstein repair			
Annual surgeon volume, (cases/year)			
≤10	4.02	1.27–12.75	0.018
11–25	3.64	1.15–11.58	0.028
26–50	3.93	1.22–12.64	0.022
51–100	4.30	1.27–14.54	0.019
>100	1		
Age	1.00	0.99–1.01	0.837
Sex, male vs. female (ref)	1.99	0.49–8.05	0.334
Type of hernia			
Lateral	1		
Medial	2.32	1.74–3.08	<.0001
Pantaloon	1.29	0.78–2.13	0.321
Combined	1.92	0.27–13.88	0.519
Method of anesthesia			
General	1		
Local	1.13	0.84–1.51	0.423
Spinal	0.68	0.17–2.74	0.586
Defect size			
EHS 1	1		
EHS 2	1.22	0.65–2.27	0.541
EHS 3	2.11	1.12–3.99	0.021
Laparoscopic TAPP repair			
Annual surgeon volume, (cases/year)			
≤10	1.89	1.29–2.77	0.001
11–25	2.08	1.43–3.01	<.0001
26–50	1.80	1.25–2.59	0.002
51–100	1.58	1.11–2.24	0.010
>100	1		
Age	1.00	0.99–1.00	0.790
Sex, male vs. female (ref)	2.31	1.45–3.68	<.0001
Type of hernia			
Lateral	1		
Medial	0.81	0.64–1.04	0.098
Pantaloon	1.00	0.65–1.55	0.999
Femoral	0.38	0.13–1.06	0.064
Combined	0.75	0.28–2.02	0.564
Defect size			
EHS 1	1		
EHS 2	0.85	0.58–1.24	0.392
EHS 3	1.99	1.34–2.97	0.001

Surgeon Volume and Risk of Reoperation after Laparoscopic Primary Ventral Hernia Repair: A Nationwide Register-Based Study

Camilla Christophersen, MS, Siv Fonnes, MD, PhD, Jason Joe Baker, MD, Kristoffer Andresen, MD, PhD, Jacob Rosenberg, MD, DSc, FACS

BACKGROUND: Repairs of primary ventral hernias are common procedures but are associated with high recurrence rates. Therefore, it is important to investigate risk factors for recurrence to optimize current treatments. The aim of this study was to assess the impact of annual surgeon volume on the risk of reoperation for recurrence after primary ventral hernia repair.

STUDY DESIGN: We conducted a nationwide register-based study with data from the Danish Ventral Hernia Database and the Danish Patient Safety Authority's Online Register linked via surgeons' authorization identification. We included patients 18 years and older, undergoing umbilical or epigastric hernia repair between 2011 and 2020. Annual surgeon volume was categorized into ≤ 9, 10 to 19, 20 to 29, and ≥ 30 cases. Patients were followed until reoperation, death, emigration, or end of the study period.

RESULTS: We included 7,868 patients who underwent laparoscopic (n = 1,529 [19%]), open mesh (n = 4,138 [53%]), or open nonmesh (n = 2,201 [28%]) repair. There was an increased risk of reoperation after laparoscopic umbilical or epigastric hernia repair for surgeons with ≤ 9 (hazard ratio 6.57; $p = 0.008$), 10 to 19 (hazard ratio 6.58; $p = 0.011$), and 20 to 29 (hazard ratio 13.59; $p = 0.001$) compared with ≥ 30 cases/y. There were no differences in risk of reoperation after open mesh and open nonmesh repair in relation to annual surgeon volume.

CONCLUSIONS: There was a significantly higher risk of reoperation after laparoscopic primary ventral hernia repair performed by lower-volume surgeons compared with high-volume surgeons. Additional research investigating how sufficient surgical training and supervision are ensured is indicated to reduce risk of reoperation after primary ventral hernia repair. (J Am Coll Surg 2021;233:346−356. © 2021 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

In primary ventral hernia repair, recurrence or reoperation rates are commonly used to assess long-term outcomes.[1] Ventral hernia repair is a common surgical procedure,[2] however, recurrences rates are still as high as 22%.[3] Reoperation rate underestimates the clinical recurrence rate, as only approximately 30% of clinical recurrences are reoperated.[4] One study found that the use of mesh halved the recurrence rate after small primary ventral hernia repairs compared with open nonmesh repairs.[5] Other factors that can influence recurrence rates after umbilical and epigastric hernia repairs are hernia defect size,[6] surgical approach,[7] use of mesh,[8] mesh placement,[9] and method of mesh fixation.[10] Surgeons with more experience and high annual volume of procedures seemed to affect reoperation rates after inguinal hernia repair[11] and incisional hernia repair.[12] The effect of annual surgeon volume on reoperation rate after primary ventral hernia repair has only been reported in 1 previous study, which indicated an impact of annual surgeon volume on reoperation rates.[13] However, this previous study did not provide data on hernia defect size, mesh placement, or fixation method, and the study cohort was based on diagnostic codes, which did not distinguish between primary and recurrent hernias.[13] Therefore, there is a need to investigate how annual surgeon volume affects outcomes

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of ventral hernia repair, with more details about the operative technique.

The aim of this study was to assess how annual surgeon volume impacts the risk of reoperation for recurrence after umbilical and epigastric hernia repair.

METHODS

This nationwide register-based study with prospectively collected data followed the RECORD (Reporting of Studies Conducted Using Observational Routine-Collected Health Data) statement.[14] We used data from the Danish Ventral Hernia Database[15] and Patient Safety Authority's Online Register.[16] The Danish Ventral Hernia Database was established in 2007 and contains patient demographic and perioperative data, which are described elsewhere.[17] The Danish Ventral Hernia Database also draws data from the Danish National Patient Registry via patients' unique personal identification (ID) number, providing data on all patient contacts with both public and private healthcare providers.[18] In addition, the Danish Ventral Hernia Database is linked with data from the Danish Civil Registration System, via patients' unique personal ID number,[19] making it possible to identify patients who emigrated or died during follow-up. The publicly available Danish Patient Safety Authority's Online Register[16] provides data on surgeons' authorization ID, authorization status, surgeon's date of birth, date of authorization, field of specialization, and date of approved specialization. In this study, patient data from the Danish Ventral Hernia Database were linked with data on surgeons from the Danish Patient Safety Authority's Online Register via surgeons' unique authorization ID.

The study period was January 2011 to January 2020 and registration of surgeon authorization ID became mandatory in the Danish Ventral Hernia Database from 2016 and onward for all repairs. Patients were followed via the database until death, reoperation, emigration, or the end of the study period (January 2020). We

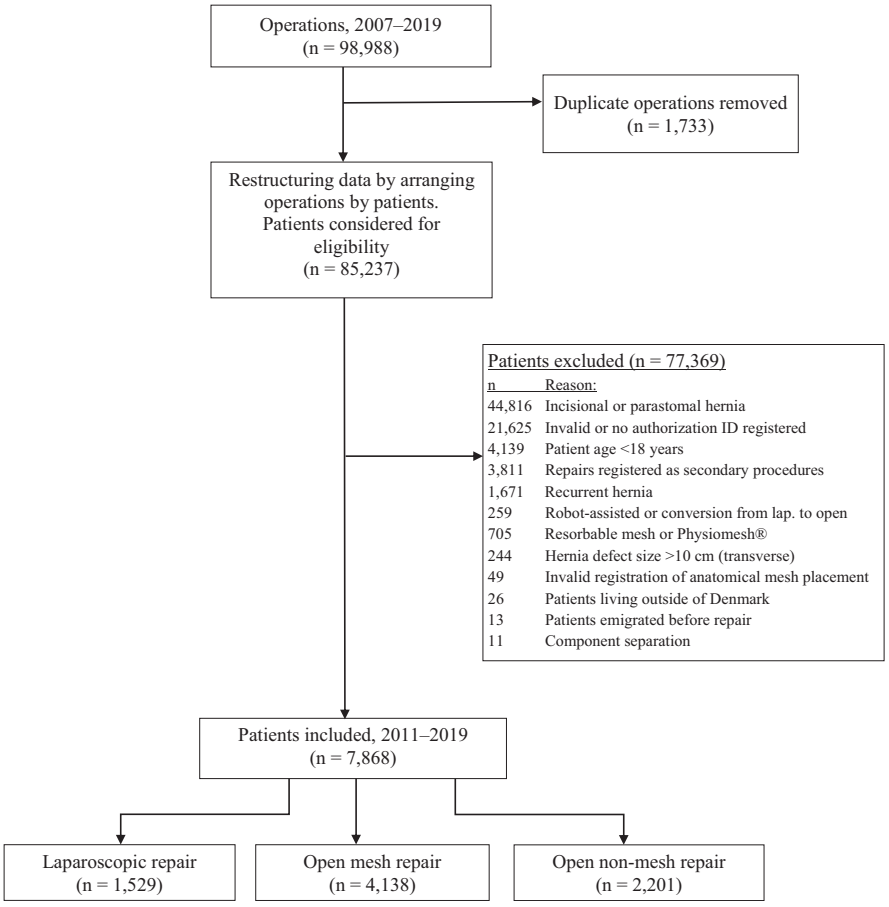


Figure 1. Flow chart depicting the study population selection.

Table 1. Patient and Operative Characteristics for the Laparoscopic Cohort

Characteristic	Total (n = 1,529)	Annual surgeon volume, cases/y				p Value
		≤ 9 (n = 506)	10–19 (n = 349)	20–29 (n = 209)	≥ 30 (n = 465)	
Patient						
Age, y, mean ± SD	54 ± 12	55 ± 12*	54 ± 11	55 ± 13*	53 ± 12	0.047
Sex, m, n (%)	1,040 (68)	348 (69)	225 (65)	141 (68)	326 (70)	0.374
BMI > 30 kg/m^2, n (%)	505 (33)	200 (40)	101 (29)	40 (19)*	164 (35)	< 0.001
Smoking status, n (%)						
Active	146 (10)	51 (10)	42 (12)	7 (3)*	46 (10)	< 0.001
Unknown	769 (44)	261 (52)*	193 (55)*	123 (59)*	102 (22)	< 0.001
Operative						
Emergency repair, n (%)	125 (8)	71 (14)*	34 (10)*	13 (6)*	7 (2)	< 0.001
Type of hernia, n (%)						
Umbilical	1,193 (78)	395 (78)*	252 (72)*	154 (74)*	392 (84)	< 0.001
Epigastric	336 (22)	111 (22)*	97 (28)*	55 (26)*	73 (16)	< 0.001
Hernia defect size, cm, median (IQR)	2 (2–3)	3 (2–3)*	2 (2–3)*	3 (2–3)	2 (2–3)	0.001
≤ 2 cm, n (%)	812 (53)	230 (46)*	178 (51)*	107 (51)*	297 (64)	< 0.001
> 2 cm, n (%)	717 (47)	276 (54)*	171 (49)*	102 (49)*	168 (36)	< 0.001
Mesh overlap, cm[†], median (IQR)	5 (4–5)	5 (5–6)*	5 (5–5)*	5 (5–5)*	4 (3–4)	< 0.001
Mesh placement, n (%)						
Intraperitoneal	1,192 (78)	484 (96)*	339 (97)*	203 (97)*	166 (36)	< 0.001
Preperitoneal	337 (22)	22 (4)*	10 (3)*	6 (1)*	299 (64)	< 0.001
Type of tack, n (%)						
Absorbable	613 (40)	225 (45)*	191 (55)*	133 (64)*	64 (14)	< 0.001
Permanent	843 (60)	270 (53)*	151 (43)*	66 (32)*	356 (77)	< 0.001
Defect closure	897 (59)	289 (57)*	248 (71)*	152 (73)*	208 (45)	< 0.001
Follow-up, mo, median (IQR)	23 (13–33)	23 (12–35)*	27 (17–35)*	29 (21–36)*	18 (10–28)	< 0.001
Crude reoperation, n (%)	36 (2)	13 (3)*	9 (3)	10 (5)*	4 (1)	0.018

The ≥ 30 cases annual volume category was used as the reference in the independent chi-square, Kruskal-Wallis, and Dunn's tests.
*$p \leq 0.05$.
[†]Minimum mesh overlap of the defect in all directions.
IQR, interquartile range.

defined reoperation as hernias registered as a reoperation or an operation for a ventral hernia after the index operation.

All patients registered in the Danish Ventral Hernia Database were assessed for eligibility. We included patients 18 years and older undergoing primary umbilical or epigastric hernia repair and undergoing either laparoscopic or open technique. Surgeons were included if they had a valid authorization ID registered. Patients were excluded if they were younger than 18 years and if the first registered operation was for recurrence. In addition, we performed a "look back" from 2007 to 2011, and patients who underwent operation for a ventral hernia previously were excluded. Patients were excluded if the index operation was an incisional or parastomal hernia, or if patients underwent operations for both umbilical and epigastric hernias on the same day. Patients were also excluded if they underwent procedures using robot-assisted techniques, were converted from laparoscopic to open technique, had a hernia defect size > 10 cm in transverse diameter, or had undergone repairs performed using resorbable mesh types or Physiomesh (because this mesh was withdrawn due to high risk of reoperation).[20] In addition, exclusion criteria were use of component separation, repairs performed as secondary procedures, open repairs with inlay mesh, patient residence outside of Denmark, or invalid surgeon authorization ID.

The primary end point was risk of reoperation or recurrence based on annual surgeon volume. The secondary outcomes were how risk of reoperation was affected by surgeon's age, which was dichotomized into younger than 45 years and 45 years and older,[21] and years since surgeon's graduation and specialization. Surgeon's annual volume was divided into 4 categories based

Table 2. Patient and Operative Characteristics for the Open Mesh Cohort

Characteristic	Total (n = 4,138)	Annual surgeon volume, cases/y				p Value
		≤ 9 (n = 2,497)	10–19 (n = 1,005)	20–29 (n = 352)	≥ 30 (n = 284)	
Patient						
Age, y, mean ± SD	53 ± 14	53 ± 14*	53 ± 14*	53 ± 14*	49 ± 13	0.001
Sex, m, n (%)	2,845 (69)	1,719 (69)*	719 (72)*	237 (67)	170 (60)	0.002
BMI > 30 kg/m^2, n (%)	975 (24)	641 (26)	205 (20)	69 (20)	60 (21)	< 0.001
Smoking status, n (%)						
Active	482 (12)	305 (12)	95 (10)*	43 (12)	39 (14)	< 0.001
Unknown	1,153 (28)	960 (38)	478 (48)*	196 (56)*	105 (37)	< 0.001
Operative						
Emergency repair, n (%)	469 (11)	363 (15)*	76 (8)*	25 (7)*	5 (2)	< 0.001
Type of hernia, n (%)						
Umbilical	3,329 (80)	2,002 (80)	831 (83)	275 (78)	221 (78)	0.123
Epigastric	809 (20)	495 (20)	174 (17)	77 (22)	63 (22)	0.123
Hernia defect size, cm, median (IQR)	2 (1–2)	2 (1–2)*	1 (1–2)	2 (1–2)*	1 (1–2)	< 0.001
≤ 2 cm, n (%)	3,681 (87)	2,143 (86)*	891 (89)	300 (85)*	258 (91)	0.019
> 2 cm, n (%)	564 (13)	354 (14)*	114 (11)	52 (15)*	26 (9)	0.019
Mesh overlap, cm†, median (IQR)	2 (1–2)	2 (2–3)*	2 (2–3)	2 (2–3)	2 (2–3)	< 0.001
Mesh placement, n (%)						
Onlay	2,585 (62)	1,726 (69)*	659 (66)*	138 (39)*	62 (22)	< 0.001
Preperitoneal	912 (22)	431 (17)*	199 (20)*	125 (36)*	157 (55)	< 0.001
Intraperitoneal	492 (12)	240 (10)*	123 (12)*	72 (21)	57 (20)	< 0.001
Sublay	149 (4)	100 (4)	24 (2)	17 (5)	8 (3)	< 0.001
Follow-up, mo, median (IQR)	19 (9–31)	17 (9–28)	23 (11–33)*	25 (14–35)*	20 (8–31)	< 0.001
Crude reoperation, n (%)	83 (2)	45 (2)	16 (2)	15 (4)	7 (3)	0.013

The ≥ 30 volume category was used as the reference in the independent chi-square, Kruskal-Wallis, and Dunn's tests.
*$p \leq 0.05$.
†Minimum mesh overlap of the defect in all directions.
IQR, interquartile range.

on annual volume: 1 low-volume category (≤ 9), 2 intermediate-volume categories (10 to 19 and 20 to 29), and 1 high-volume category (≥ 30). This categorization was based on a previous study investigating annual surgeon volume and outcomes of ventral hernia repair.[13] The annual surgeon volume was calculated as the number of repairs performed during the year before the index repair. This allowed annual surgeon volume to be a dynamic variable, making it possible for surgeons to change volume category. During the first year of the study period, the number of repairs from the current calendar year was used to calculate the annual surgeon volume for each surgeon because surgeons' authorization IDs for the previous year were not available. The data on surgeons were presented for the volume category in which the individual surgeon performed most of their repairs.

Patients were divided into the following 3 cohorts: laparoscopic, open mesh, and open nonmesh. We performed a subgroup analysis dichotomizing hernia defect size into ≤ 2 cm and > 2 cm.[22] In addition, sensitivity analyses were conducted that investigated how the calculation of annual surgeon volume impacted outcomes.

The statistical analyses were carried out in SPSS, version 25.0 (IBM Corp). The distribution of continuous data was assessed visually with Q-Q plots and histograms. Normally distributed data were presented as mean ± SD. Not normally distributed data were presented as median (interquartile range [IQR]). Continuous data were analyzed using the nonparametric Kruskal-Wallis and Dunn's tests. Categorical data were analyzed using the independent chi-square test, with surgeons performing ≥ 30 repairs annually as the reference group. A p value ≤ 0.05 was assessed as significant. We performed multivariate analyses using the Cox proportional hazard analysis, presented as hazard ratio (HR) with 95% CI. In Cox proportional hazard analysis, a rule of thumb is to adjust for 1 variable per approximately 10 events.[23] Through backward stepwise elimination, with $p = 0.2$ as the cutoff, we chose to adjust for anatomic mesh placement, type of tacks, and

emergency vs elective repair in the laparoscopic cohort. In the open mesh cohort, the multivariate analysis was adjusted for anatomic mesh placement; emergency vs elective repair; hernia defect size; and patient's sex, age, BMI, and smoking status. In the open nonmesh cohort, the multivariate analysis was adjusted for emergency vs elective repair; hernia defect size; and patient's sex, age, BMI, and smoking status. Surgeons performing ≥ 30 cases/y were used as the reference group in the multivariate analyses. Kaplan-Meier plots were used to illustrate the cumulative reoperation rates.

This study was approved by the Danish Clinical Quality Program (RKKP) and the Danish Data Protection Agency (P-2020-380). According to Danish law, approval from ethics committees and informed written consent from participants were not required.

RESULTS

We included 7,868 patients undergoing primary umbilical or epigastric hernia repair by means of laparoscopic (n = 1,529 [19%]), open mesh (n = 4,138 [53%]), or open nonmesh (n = 2,201 [28%]) repair. A flow chart of the study population selection is shown in Figure 1. The patient and operative characteristics are shown in Table 1 for the laparoscopic cohort, in Table 2 for the open mesh cohort, and in Table 3 for the open nonmesh repair cohort. The high-volume category surgeons performing ≥ 30 cases/y repaired small (≤ 2 cm) hernias more frequently than hernias > 2 cm in the laparoscopic (64%), open mesh (91%), and open nonmesh (100%) cohorts. These high-volume surgeons performed few emergency repairs in the laparoscopic (2%), open mesh (2%), and open nonmesh cohorts (0%). In all 3 cohorts, the low- and intermediate-volume category surgeons performed most of the emergency repairs. The median follow-up for the laparoscopic, open mesh, and open nonmesh cohorts were 23 (IQR 13 to 33) months, 19 (IQR 9 to 31) months, and 26 (IQR 13 to 35) months, respectively. We included 725 surgeons and the characteristics of included surgeons are shown in Table 4.

The risk of reoperation after laparoscopic umbilical and epigastric repairs was significantly increased when performed by surgeons with an annual volume of ≤ 9 (HR 6.57; p = 0.008), 10 to 19 (HR 6.58; p = 0.011), and 20 to 29 (HR 12.59; p = 0.001) compared with ≥ 30 cases (Table 5). The Cox proportional hazard analysis was adjusted for anatomic mesh placement, type of tacks, and emergency vs elective repair, and is presented in eTable 1. The cumulative reoperation rates for the surgeon volume categories are shown in Figure 2A. High-volume surgeons placed the mesh preperitoneally (64%) (p < 0.001) and surgeons in the low- and intermediate-volume categories of ≤ 9 (96%), 10 to 19 (97%), and 20 to 29 (97%)

Table 3. Patient and Operative Characteristics for the Open Nonmesh Cohort

Characteristic	Total (n = 2,201)	Annual surgeon volume, cases/y ≤ 9 (n = 1,593)	10–19 (n = 431)	20–29 (n = 63)	≥ 30 (n = 114)	p Value
Patient						
Age, y, mean ± SD	47 ± 15	46 ± 15	48 ± 15	47 ± 13	49 ± 14	0.086
Sex, m, n (%)	1,187 (54)	822 (52)*	250 (58)	43 (68)	72 (63)	0.001
BMI > 30 kg/m^2, n (%)	234 (11)	169 (11)	45 (10)	4 (6)	16 (14)	< 0.001
Smoking status, n (%)						
Active	167 (8)	139 (9)	18 (4)	3 (5)	7 (6)	< 0.001
Unknown	1,178 (54)	856 (54)*	264 (61)*	36 (57)*	22 (19)	< 0.001
Operative						
Emergency repair, n (%)	300 (14)	273 (17)	25 (6)	2 (3)	0	< 0.001
Type of hernia, n (%)						
Umbilical	1,673 (76)	1,205 (76)	336 (78)	47 (75)	85 (75)	0.750
Epigastric	528 (24)	388 (24)	95 (22)	16 (25)	29 (25)	0.750
Hernia defect size, cm, median (IQR)	1 (1–1)	1 (1–1)*	1 (1–1)*	1 (1–1)*	1 (1–1)	0.002
≤ 2 cm, n (%)	2,103 (96)	1,503 (94)	424 (98)	62 (98)	114 (100)	< 0.001
> 2 cm, n (%)	98 (4)	90 (6)	7 (2)	1 (2)	0	< 0.001
Follow-up, mo, median (IQR)	26 (13–35)	25 (13–35)*	31 (20–37)*	30 (8–36)*	20 (5–28)	< 0.001
Crude reoperation, n (%)	104 (5)	75 (5)	21 (5)	2 (3)	6 (4)	0.934

The ≥ 30 volume category was used as the reference in the independent chi-square, Kruskal-Wallis, and Dunn's tests.
*p ≤ 0.05.
IQR, interquartile range.

Table 4. Characteristics of Included Surgeons*

Characteristic	Total	Annual surgeon volume, cases/year			
		≤ 9	10–19	20–29	≥ 30
Laparoscopic					
Surgeons, n	209	167	26	12	4
Age, y, median (IQR)	42 (36–52)	40 (34–50)	50 (41–59)	53 (42–62)	48 (46–54)
Younger than 45 y, n (%)	115 (55)	102 (61)	9 (35)	4 (33)	0
45 y or older, n (%)	94 (45)	65 (39)	17 (65)	8 (67)	4 (100)
Years since, median (IQR)					
Graduation	11 (7–22)	10 (5–18)	21 (12–29)	20 (12–33)	21 (14–25)
Specialization	6 (2–11)	5 (1–11)	9 (3–13)	7 (3–13)	10 (8–15)
Surgeon currently not specialized, n (%)	68 (33)	66 (40)	1 (4)	1 (8)	0
Open mesh					
Surgeons, n	592	505	66	14	7
Age, median (IQR)	36 (31–44)	36 (30–43)	37 (32–46)	54 (51–60)	56 (48–61)
Younger than 45 y, n (%)	448 (76)	398 (79)	47 (71)	3 (21)	0
45 y or older, n (%)	144 (24)	107 (21)	19 (29)	11 (79)	7 (100)
Years since, median (IQR)					
Graduation	6 (2–13)	6 (2–12)	8 (3–13)	25 (11–31)	27 (18–33)
Specialization	6 (1–13)	6 (1–12)	7 (1–14)	13 (9–22)	10 (7–15)
Surgeon currently not specialized, n (%)	359 (61)	320 (63)	37 (56)	2 (14)	0
Open nonmesh					
Surgeons, n	514	482	27	†	3
Age, median (IQR)	37 (32–48)	37 (32–47)	37 (34–55)	—	60 (52–63)
Younger than 45 y, n (%)	364 (71)	348 (72)	16 (59)	—	0
45 y or older, n (%)	150 (29)	134 (28)	11 (41)	—	3 (100)
Years since, median (IQR)					
Graduation	8 (3–15)	8 (3–15)	7 (2–27)	—	33 (19–35)
Specialization	6 (2–14)	6 (2–13)	13 (5–17)	—	18 (10–22)
Surgeon currently not specialized, n (%)	289 (56)	275 (57)	14 (52)	—	0

*Surgeon data are presented for the volume category in which the individual surgeon performed repairs most frequently.
†Data not reported for the open nonmesh cohort because the number of surgeons in these categories was too low to ensure anonymity.
IQR, interquartile range.

used intraperitoneal mesh placement significantly more frequently compared with surgeons in the ≥ 30 volume category (36%) ($p < 0.001$). Low- (45%) and intermediate-volume surgeons (55% and 64%) used absorbable tacks significantly more frequently compared with high-volume surgeons (14%) ($p < 0.001$), and the high-volume surgeons used permanent tacks (75%) significantly more frequently compared with the lower-volume categories (29% to 50%) ($p < 0.001$). In addition, low- and intermediate-volume surgeons of ≤ 9 (57%), 10 to 19 (71%), and 20 to 29 (73%) cases/y used defect closure significantly more frequently compared with high-volume surgeons (45%) ($p < 0.001$).

Annual surgeon volume did not impact the risk of reoperation after open mesh umbilical or epigastric repairs compared with high-volume surgeons, as is shown in Table 5. Annual volume of ≤ 9 and 10 to 19 cases seemed to have a lower risk of reoperation, and 20 to 29 cases seemed to have a higher risk of reoperation after open mesh umbilical or epigastric hernia repair compared with ≥ 30 cases. The Cox proportional hazard analysis was adjusted for mesh placement, emergency vs elective repair, hernia defect size, patient's sex, age, BMI, and smoking status, and is shown in eTable 1. The cumulative reoperation rates separated for the annual surgeon volume categories are shown in Figure 2B. The majority of open mesh repairs were performed by surgeons in the ≤ 9 (60%) and 10 to 19 (20%) cases/y categories. Surgeons in the low- and intermediate-volume categories of ≤ 9 (69%), 10 to 19 (66%), and 20 to 29 (39%) placed the mesh as onlay more frequently compared with those in the ≥ 30 cases/y category (22%) ($p < 0.001$). High-volume surgeons used preperitoneal mesh placement (55%) more often.

Annual surgeon volume did not impact the risk of reoperation compared with high-volume surgeons for open nonmesh repair (Table 5). The Cox proportional hazard

Table 5. Risk of Reoperation Based on Annual Surgeon Volume Assessed with Cox Proportional Hazard Analyses*

Surgeon volume	Hazard ratio	95% CI	p Value
Laparoscopic repair†			
≤ 9 cases/y	6.57	1.63–26.46	0.008
10–19 cases/y	6.58	1.53–28.22	0.011
20–29 cases/y	13.59	3.05–60.61	0.001
≥ 30 cases/y	1	—	—
Open mesh repair‡			
≤ 9 cases/y	0.98	0.42–2.28	0.966
10–19 cases/y	0.75	0.30–1.88	0.544
20–29 cases/y	1.65	0.67–4.10	0.278
≥ 30 cases/y	1	—	—
Open nonmesh repair§			
≤ 9 cases/y	0.68	0.29–1.59	0.371
10–19 cases/y	0.61	0.24–1.54	0.299
20–29 cases/y	0.47	0.09–2.34	0.354
≥ 30 cases/y	1	—	—

*The number of variables adjusted for in the analyses depended on the number of events in the respective cohorts.
†Adjusted for elective vs emergency repair, mesh placement, and type of tack used.
‡Adjusted for age, sex, BMI, smoking status, elective vs emergency repair, mesh placement, and hernia defect size.
§Adjusted for age, sex, BMI, smoking status, elective vs emergency repair, and hernia defect size.

analysis was adjusted for emergency vs elective repair, hernia defect size, patients' sex, age, BMI, and smoking status, as shown in eTable 1. The cumulative reoperation rates for each annual surgeon volume category are shown in Figure 2C. Most of the repairs in this cohort were performed by surgeons with ≤ 9 (72%) and 10 to 19 (20%) cases/y.

In addition, analyses were conducted to investigate secondary outcomes. Firstly, we investigated how surgeon's age dichotomized into younger than 45 years and 45 years and older affected the crude reoperation rate. In the open mesh cohort, there was a significant difference in the reoperation rates for surgeons younger than 45 years (1.5%) and 45 years and older (2.8%) ($p = 0.006$). In the laparoscopic ($p = 0.387$) and open nonmesh ($p = 0.683$) cohorts, there were no significant differences in the crude reoperation rates between surgeons younger than 45 years and 45 years and older. Secondly, we analyzed how the number of years since surgeon's graduation affected the risk of reoperation. The number of years since surgeon's graduation was associated with significantly increased risk of reoperation after open mesh repair. Thirdly, we investigated how the number of years since surgeon's specialization affected the risk of reoperation after umbilical or epigastric hernia repair. The number of years since surgeon's specialization did not impact the risk of reoperation.

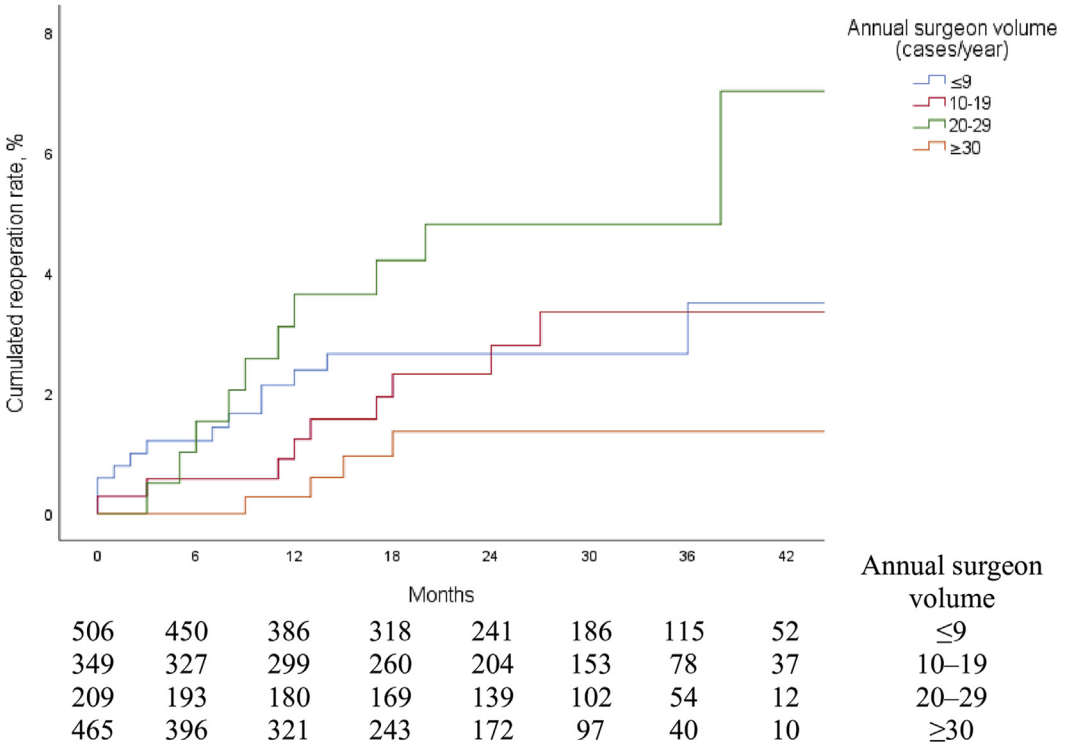
Subgroup analyses were performed for hernia defect size ≤ 2 cm and > 2 cm. We found an increased risk of reoperation based on annual surgeon volume after laparoscopic repair of umbilical and epigastric hernias of ≤ 2 cm (eTable 2).

Lastly, sensitivity analyses were conducted from which repairs performed during the first year of the individual surgeon's operating career were excluded. In the laparoscopic cohort, the sensitivity analyses showed a similar increased risk of reoperation for all categories of lower-volume surgeons compared with high-volume surgeons, but results were only significant for the 20 to 29 cases/y volume category (HR 7.86; $p = 0.012$). For the open mesh and open nonmesh cohorts, the tendencies were similar to the primary analyses of risk of reoperation across the annual volume categories (analyses not shown).

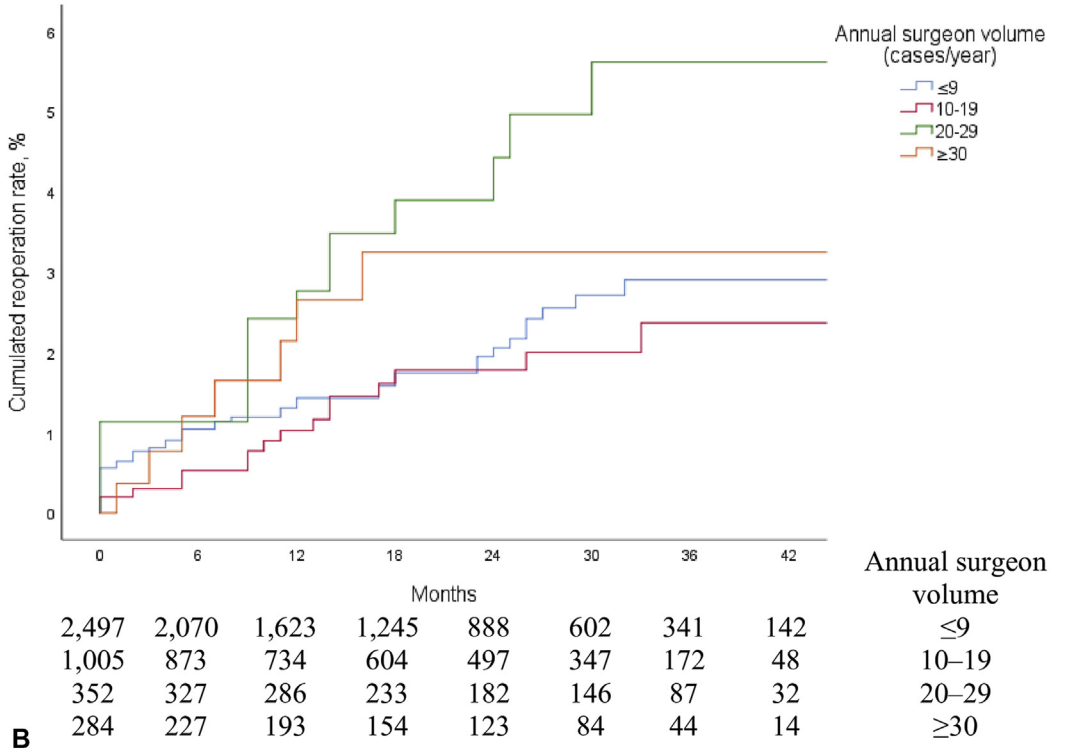
DISCUSSION

In this nationwide register-based study, we found that annual surgeon volume of < 30 cases was associated with a higher risk of reoperation after laparoscopic repair of umbilical and epigastric hernias compared with high-volume surgeons of ≥ 30 cases. Annual surgeon volume did not seem to impact the risk of reoperation after open mesh and open nonmesh repair of umbilical and epigastric hernias.

To our knowledge, only 1 previous study reported annual surgeon volume and risk of reoperation after primary ventral hernia repairs. In that study, the authors found a decreased risk of reoperation for both laparoscopic and open primary ventral hernia repairs performed by high-volume surgeons of ≥ 30 cases/y compared with



A



B

Figure 2. Kaplan-Meier plots showing the (A) cumulative reoperation rate after laparoscopic repair of primary ventral hernia reported based on annual surgeon volume ($p = 0.070$) and the number of patients. (B) Cumulative reoperation rate after open mesh repair of primary ventral hernia reported based on annual surgeon volume ($p = 0.047$) and number of patients.(C) Cumulative reoperation rate after open nonmesh repair of primary ventral hernia reported based on annual surgeon volume ($p = 0.792$) and number of patients.

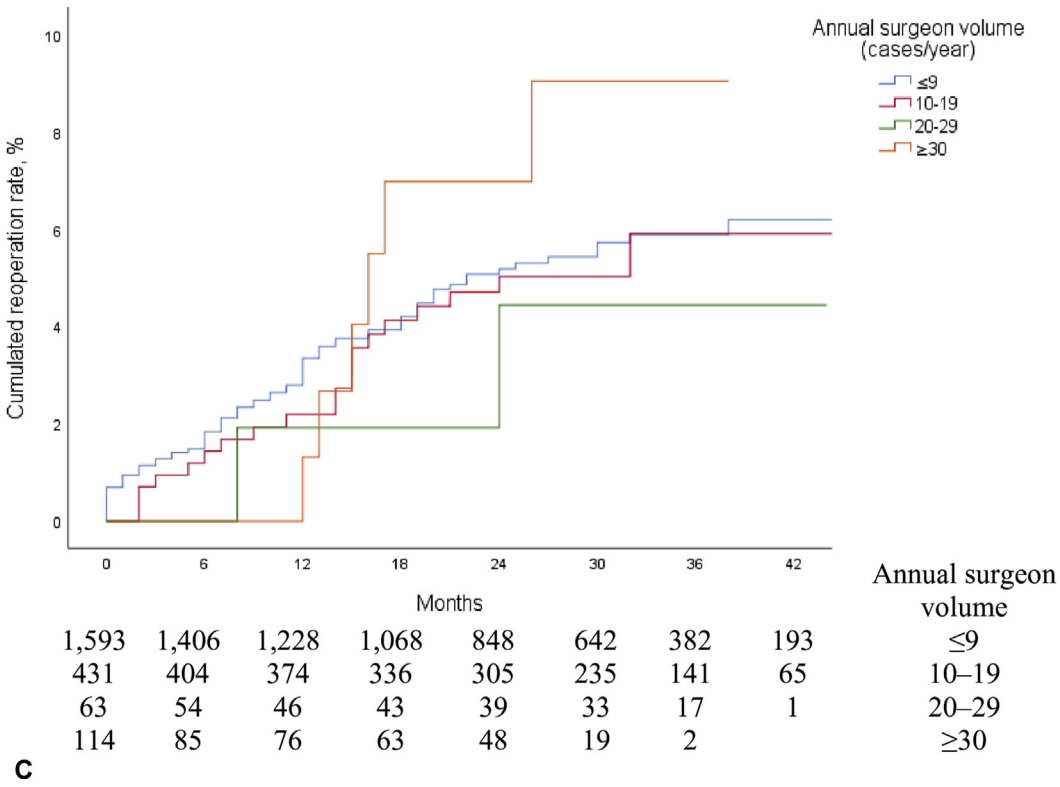


Figure 2. continue

low-volume surgeons of ≤ 9 cases/y.[13] However, they did not adjust for the different anatomic mesh placements in their analyses, making it difficult to directly compare their findings with our study population. Interestingly, in the open mesh cohort, we found that high-volume surgeons primarily placed the mesh preperitoneally and low-volume surgeons placed the mesh as onlay. Preperitoneal mesh placement is a more complex procedure because it requires dissection of the preperitoneal space,[24] and this might explain why high-volume surgeons performed most of these repairs. According to current guidelines, the mesh should be placed preperitoneal in open repair when feasible, as it reduces the risk of reoperation and complications compared with other mesh placements[1]; however, the strength of recommendation in the guideline was graded as weak. Therefore, it is important to ensure adequate training and education, enabling younger surgeons and surgeons with lower annual volume to perform preperitoneal mesh placement. In addition, we found that most of the laparoscopic preperitoneal mesh repairs were performed by high-volume surgeons, and lower-volume surgeons in the laparoscopic cohort placed the mesh intraperitoneally. In the laparoscopic cohort, high-volume surgeons primarily used permanent tacks, and intermediate-volume surgeons used absorbable tacks more frequently. Absorbable tacks are associated with an increased risk of reoperation[3,10] and use of permanent tacks is recommended.[1] The increased risk of reoperation after laparoscopic umbilical or epigastric hernia repair performed by lower-volume surgeons compared with high-volume surgeons could perhaps be explained by insufficient training and supervision of lower-volume surgeons in our laparoscopic cohort. However, surgical training and supervision is outside the scope of the current study, and additional research is needed to investigate how sufficient surgical training and supervision are ensured. In the open mesh and open nonmesh repair cohorts, the high-volume surgeons performed few of the repairs. The majority of repairs in these cohorts were performed by surgeons in the lower-volume categories. It is important to ensure adequate supervision of lower-volume surgeons performing umbilical and epigastric hernia repair.

There are several strengths to this nationwide register-based study. The Danish Ventral Hernia Database has nationwide coverage and includes both public and private hospitals and approximately 80% of ventral hernia repairs performed in Denmark are registered in the database,[15] reducing the risk of selection bias of included patients. In addition, the follow-up on patients in the Danish

Ventral Hernia Database is close to 100%[15] because the database holds data from the Danish National Patient Registry[18] and the Danish Civil Registration System.[19] Another strength of this study was that we only included primary ventral hernia repairs because differences between primary ventral and incisional hernias have been reported for both surgical management and outcomes.[25] In addition, this study used the specific annual surgeon volume and not hospital volume as an indirect measure of surgeon's annual volume, and the annual surgeon volume categories were defined according to pre-existing literature.[13] The annual surgeon volume was calculated as a dynamic variable that allowed surgeons to change volume categories during the study period, reflecting the varying nature of the number of repairs the individual surgeon performs throughout a 4-year period. The variables adjusted for in the Cox proportional hazard analyses were chosen through backward stepwise elimination, ensuring that the multivariate analyses were adjusted for the relevant covariates, and the multivariate analyses were adjusted for operative characteristics known to affect the risk of reoperation. Yet, the study size was limited by the data availability of surgeons' authorization IDs in the Danish Ventral Hernia Database, which was mandatory from 2016 and onward. Data on patients' BMI and smoking status were only available for 68% of the included patients. The Danish Ventral Hernia Database includes few robot-assisted hernia repairs because this technique is not used frequently in Denmark, therefore, it was not possible to investigate the impact of annual surgeon volume on robot-assisted ventral hernia repair outcomes in this study population. The impact of annual surgeon volume on outcomes after robot-assisted ventral hernia repair should be investigated in a population in which the technique is used more frequently. Another limitation to this study was that we used reoperation rate as a measure for recurrence rate. A previous study found that reoperation rate underestimates the clinical recurrence rate, as only approximately 30% of clinical recurrences are reoperated.[4] Lastly, there was a risk of a statistical type 2 error in the analyses of the cohorts for open mesh and nonmesh, and it is therefore possible that our findings would reach statistical significance in a larger sample size.

CONCLUSIONS

We found a higher risk of reoperation after laparoscopic umbilical and epigastric hernia repairs performed by low- and intermediate-volume surgeons compared with high-volume surgeons. This might raise a discussion of centralization of laparoscopic umbilical and epigastric hernia repairs on fewer surgeons with high annual volumes to ensure better long-term outcomes for patients. However, factors such as surgical training and geography can impact the feasibility of centralizing laparoscopic umbilical and epigastric hernia repair. We found no significant impact of annual surgeon volume on risk of reoperation after open mesh and open nonmesh repair of umbilical and epigastric repairs.

Author Contributions

Study conception and design: Christophersen, Fonnes, Andresen, Rosenberg
Acquisition of data: Andresen
Analysis and interpretation of data: Christophersen, Baker, Andresen
Drafting of manuscript: Christophersen
Critical revision: Christophersen, Fonnes, Baker, Andresen, Rosenberg

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eTable 1. Risk of Reoperation Based on Annual Surgeon Volume Assessed with Cox Proportional Hazard Analyses for the Laparoscopic, Open Mesh, and Open Nonmesh Cohorts with Adjusted Covariates

Repair	Hazard ratio	95% CI	p Value
Laparoscopic			
Annual surgeon volume			
≤ 9 cases	6.57	1.63–26.46	0.008
10–19 cases	6.58	1.53–28.22	0.011
20–29 cases	13.59	3.05–60.61	0.001
≥ 30 cases	1	—	—
Elective vs emergency repair			
Emergency	2.71	1.64–6.32	0.021
Elective	1	—	—
Mesh placement			
Intraperitoneal	0.25	0.08–0.77	0.016
Preperitoneal	1	—	—
Type of tack			
Absorbable	0.60	0.29–1.24	0.169
Permanent	1	—	—
Open mesh			
Annual surgeon volume			
≤ 9 cases	0.98	0.42–2.28	0.966
10–19 cases	0.75	0.30–1.88	0.544
20–29 cases	1.65	0.67–4.10	0.278
≥ 30 cases	1	—	—
Age, y	0.99	0.98–1.01	0.446
Sex			
Female	1.73	1.11–2.70	0.015
Male	1	—	—
BMI			
> 30 kg/m^2	0.74	0.36–1.53	0.415
≤ 30 kg/m^2	1	—	—
Smoking status			
Active	0.46	0.14–1.53	0.207
Nonactive	1	—	—
Elective vs emergency repair			
Emergency	1.49	0.79–2.81	0.216
Elective	1	—	—
Mesh placement			
Onlay	0.66	0.38–1.14	0.134
Sublay	1.71	0.63–4.62	0.292
Intraperitoneal	1.11	0.60–2.07	0.742
Preperitoneal	1	—	—
Hernia defect size, cm	0.89	0.70–1.14	0.351
Open nonmesh			
Annual surgeon volume			
≤ 9 cases	0.68	0.29–1.59	0.371
10–19 cases	0.61	0.24–1.54	0.299
20–29 cases	0.47	0.09–2.34	0.354
≥ 30 cases	1	—	—
Age, y	1.00	0.98–1.01	0.435

(Continued)

eTable 1. Continued

Repair	Hazard ratio	95% CI	p Value
Sex			
Female	1.34	0.87–1.96	0.194
Male	1	—	—
BMI			
> 30 kg/m^2	1.47	0.73–2.95	0.276
≤ 30 kg/m^2	1	—	—
Smoking status			
Active	0.69	0.24–1.96	0.484
Nonactive	1	—	—
Elective vs emergency repair			
Emergency	0.88	0.48–1.64	0.693
Elective	1	—	—
Hernia defect size, cm	1.13	1.00–1.29	0.060

eTable 2. Subgroup Analyses of Umbilical or Epigastric Hernia ≤ 2 cm*

Repair	Hazard ratio	95% CI	p Value
Laparoscopic			
Annual surgeon volume			
≤ 9 cases	9.31	1.89–45.89	0.006
10–19 cases	9.50	1.86–48.46	0.007
20–29 cases	21.92	3.79–126.97	0.001
≥ 30 cases	1	—	—
Elective vs emergency repair			
Emergency	5.91	2.28–15.36	< 0.001
Elective	1	—	—
Mesh placement			
Intraperitoneal	0.14	0.04–0.44	0.001
Preperitoneal	1	—	—
Type of tack			
Absorbable	0.52	0.19–1.39	0.194
Permanent	1	—	—
Open mesh			
Annual surgeon volume			
≤ 9 cases	0.83	0.35–1.97	0.674
10–19 cases	0.73	0.29–1.83	0.498
20–29 cases	1.12	0.42–2.98	0.823
≥ 30 cases	1	—	—
Age, y	0.99	0.97–1.01	0.183
Sex			
Female	1.97	1.22–3.19	0.006
Male	1	—	—
BMI			
> 30 kg/m^2	0.72	0.32–1.59	0.414
≤ 30 kg/m^2	1	—	—
Smoking status			
Active	0.17	0.02–1.28	0.086
Nonactive	1	—	—
Elective vs emergency repair			
Emergency	1.41	0.69–2.88	0.349
Elective	1	—	—
Mesh placement			
Onlay	0.87	0.47–1.60	0.647
Sublay	2.54	0.83–7.73	0.101
Intraperitoneal	1.67	0.86–3.27	0.131
Preperitoneal	1	—	—
Hernia defect size, cm	1.00	0.62–1.63	0.989
Open nonmesh			
Annual surgeon volume			
≤ 9 cases	0.69	0.29–1.62	0.390
10–19 cases	0.60	0.24–1.51	0.275
20–29 cases	0.46	0.09–2.33	0.350
≥ 30 cases	1	—	—
Age, y	0.99	0.98–1.01	0.271

(Continued)

eTable 2. Continued

Repair	Hazard ratio	95% CI	p Value
Sex			
Female	1.20	0.79−1.84	0.395
Male	1	—	—
BMI			
> 30 kg/m^2	1.43	0.67−3.04	0.357
≤ 30 kg/m^2	1	—	—
Smoking status			
Active	0.84	0.29−2.43	0.751
Nonactive	1	—	—
Elective vs emergency repair			
Emergency	0.63	0.29−1.37	0.244
Elective	1	—	—
Hernia defect size, cm	1.37	0.88−2.13	0.169

*Risk of reoperation based on annual surgeon volume assessed with Cox proportional hazard analyses for the laparoscopic, open mesh, and open nonmesh cohorts with the adjusted covariates.

JAMA Surgery | Original Investigation

Risk of Reoperation for Recurrence After Elective Primary Groin and Ventral Hernia Repair by Supervised Residents

Camilla Christophersen, MS; Siv Fonnes, MD, PhD; Kristoffer Andresen, MD, PhD; Jacob Rosenberg, MD, DSc

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Supplemental content

IMPORTANCE Surgical training involves letting residents operate under supervision. Since hernia repair is a common procedure worldwide, it is a frequent part of the surgical curriculum.

OBJECTIVE To assess the risk of reoperation for recurrence after elective primary groin and ventral hernia repair performed by supervised residents compared with that by specialists.

DESIGN, SETTING, AND PARTICIPANTS This nationwide register-based cohort study included data from January 2016 to September 2021. Patients were followed up until reoperation, emigration, death, or the end of the study period. The study used data from the Danish Inguinal and Ventral Hernia Databases linked with data from the Danish Patient Safety Authority's Online Register via surgeons' unique authorization ID. The cohort included patients aged 18 years or older who underwent primary elective hernia repairs performed by supervised residents or specialists for inguinal, femoral, epigastric, or umbilical hernias. Hernia repairs were divided into the following 4 groups: Lichtenstein groin, laparoscopic transabdominal preperitoneal (TAPP) groin, open ventral, and laparoscopic ventral.

EXPOSURES Hernia repairs performed by supervised residents vs specialists.

MAIN OUTCOMES AND MEASURES Reoperation for recurrence, analyzed separately for all 4 groups.

RESULTS A total of 868 specialists and residents who performed 31 683 primary groin and 7777 primary ventral hernia repairs were included in this study. The median age of patients who underwent hernia repair was 60 years (IQR, 48-70 years), and 33 424 patients (84.7%) were male. There was no significant difference in the adjusted risk of reoperation after Lichtenstein groin hernia repair (hazard ratio [HR], 1.26; 95% CI, 0.99-1.59), laparoscopic groin hernia repair (HR, 1.01; 95% CI, 0.73-1.40), open ventral hernia repair (HR, 0.89; 95% CI, 0.61-1.29), and laparoscopic ventral hernia repair (HR, 2.96; 95% CI, 0.99-8.84) performed by supervised residents compared with those by specialists. There was, however, a slightly increased unadjusted, cumulative reoperation rate after Lichtenstein repairs performed by supervised residents compared with those by specialists (4.8% vs 4.2%; $P = .048$).

CONCLUSIONS AND RELEVANCE The findings of this study suggest that neither open nor laparoscopic repair of groin and ventral hernias performed by supervised residents appeared to be associated with a higher risk of reoperation for recurrence compared with the operations performed by specialists. This indicates that residents may safely perform elective hernia repair when supervised as part of their training curriculum.

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Surgical training involves letting residents operate under the supervision of an experienced surgeon. However, there are concerns that supervised residents perform poorly with poorer outcomes for patients, such as higher recurrence rates after hernia repair. Annual surgeon volume has been shown to be associated with the quality of hernia repair, and low-volume surgeons have been associated with higher risks of reoperation after repair of primary groin and ventral hernia repair.[1,2] Furthermore, studies by our group[1,2] have previously shown in the Danish Inguinal and Ventral Hernia Databases (hereinafter, the Danish Hernia Databases) that low-volume surgeons were, for the most part, inexperienced or still in their general surgery residency. Hernia repair is a part of the general surgery training curriculum in many countries since it is a common procedure worldwide.[3] Residents in general surgery must perform procedures to master the surgical techniques and overcome their learning curve.[4-7] It is therefore important to ensure that surgical residents can perform hernia repairs with acceptable reoperation rates. The aim of this study was to assess the risk of reoperation due to recurrence after elective primary inguinal, femoral, umbilical, and epigastric hernia repairs performed by supervised residents compared with those performed by specialists.

Key Points

Question Is there an increased risk of reoperation for recurrence after elective primary groin and ventral hernia repair performed by supervised residents?

Findings This Danish nationwide cohort study analyzed 31 683 primary groin and 7777 primary ventral hernia repairs performed by 868 supervised residents and specialists. There was no difference in the adjusted risk of recurrence-related reoperation after elective open and laparoscopic repair of primary groin or ventral hernias performed by supervised residents compared with those performed by specialists.

Meaning The findings of this study suggest that supervised residents can safely perform elective open and laparoscopic repair of primary groin and ventral hernias without increased risk of reoperation.

Methods

Data Sources

This was a retrospective register-based cohort study based on prospectively collected data from the Danish Hernia Databases and the Patient Safety Authority's Online Register. The study was reported according to the Reporting of Studies Conducted Using Observational Routinely Collected Health Data (RECORD) statement.[8] This study was approved by the Danish Data Protection Agency and the Danish Clinical Quality Program. According to Danish law, approval from ethics committees and informed written consent from patients, residents, or specialists were not required. Data on specialists and residents were anonymized before analyses and presentation.

All Danish health professionals have a unique authorization ID, making it possible to obtain data on residents and specialists from the publicly available Patient Safety Authority's Online Register.[9] This online register contains data on health professionals' date of birth, date of authorization, specialty, and date of specialization, allowing identification of health professionals as specialized surgeons or residents. Data on hernia repairs were retrieved from the Danish Inguinal Hernia Database[10] and Ventral Hernia Database[11] established in 1998 and 2007, respectively. Both databases include data from the public as well as private health sectors. The variables available in the Danish Hernia Databases have been described elsewhere.[12] The Danish Hernia Databases do not contain data on patients' race and ethnicity. Since 2016, the Danish Hernia Databases include the specialists' or residents' unique authorization ID as well as the variable for supervision, which was dichotomized into yes and no responses. The Danish Hernia Databases were linked with the Patient Safety Authority's Online Register via specialists' or residents' unique authorization ID.

The study period was from January 1, 2016, to September 16, 2021, and began when the supervision variable became a required entry field in the Danish Hernia Databases. Patients were followed up via the databases until reoperation for recurrence, emigration, death, or the end of the study period, whichever came first. The Danish Hernia Databases draw data from the Danish National Patient Registry[13] and Civil Registration System.[14] This ensured full follow-up of the included hernia repairs since the Danish National Patient Registry includes all operations, and thus all reoperations, and the Danish Civil Registration System includes all deaths and emigrations.

A valid entry of authorization ID in the Danish Hernia Databases was the eligibility criterion for specialists and residents in this study. We included primary elective repairs of inguinal, femoral, umbilical, and epigastric hernias performed by supervised residents or unsupervised specialists on patients aged 18 years or older. Patients were required to live in Denmark at the time of the repair. Groin hernia repairs performed with the Lichtenstein or laparoscopic transabdominal preperitoneal (TAPP) approach were included since TAPP makes up more than 98% of all laparoscopic groin hernia repairs in Denmark.[15] Ventral hernia repairs performed with open or laparoscopic approaches were included. Furthermore, the included hernia repairs were required to have a valid entry in the supervision variable, thus excluding entries with missing data. Repairs were excluded if a laparoscopic approach was converted to open. In addition, ventral hernia repairs were excluded based on operative characteristics known to be associated with increased recurrence rates: ventral hernia repairs with a transverse defect size greater than 10 cm, repairs performed as secondary procedures, use of component separation, use of resorbable mesh, and use of Physiomesh (Ethicon) since this coated polypropylene mesh was withdrawn due to higher rates of recurrence.[16] Furthermore, ventral hernia repairs with an invalid registration of the anatomical mesh placement were excluded. To ensure that the included

patients were operated on for primary hernias, we performed a "look-back" from the implementation of both databases, and a groin or ventral hernia repair prior to the index operation was considered a reoperation and excluded. The look-back was performed separately from the implementation of the Danish Inguinal Database from 1998 onward, and in the Ventral Hernia Database from 2007 onward.[12]

Outcome Measure

The outcome of interest was the reoperation rate and risk of reoperation due to recurrence after repairs performed by supervised residents vs specialists. We considered repairs performed by supervised residents since these repairs represent repairs performed with a training or educational purpose. Supervision was defined as a supervisor being present in the operating room, which is registered by the primary surgeon. However, the extent of supervision was not available from the Danish Hernia Databases and may have ranged from an unscrubbed supervisor present to a scrubbed supervisor assisting the primary surgeon. The databases do not include information about the supervising surgeon, but only the primary surgeon. The specialists were used as the reference group, and they were defined as surgeons who had achieved their specialization in gastrointestinal surgery or general surgery at the time of operation. We assumed that the specialists were experienced with hernia repair since they were not supervised. The included primary hernias were divided into 4 groups: Lichtenstein groin, laparoscopic TAPP groin, open ventral, and laparoscopic ventral hernia repair. Reoperation was defined as a subsequent operation of the same type (groin or ventral) of hernia in the same location.

Statistical Analysis

The statistical analyses were conducted in SPSS, version 25.0 (IBM). All analyses were performed separately for the primary Lichtenstein groin, laparoscopic TAPP groin, open ventral, and laparoscopic ventral hernia repairs. Histograms and Q-Q plots were used to evaluate the distribution of continuous data. Median and IQR were used to describe nonnormally distributed data. Continuous data were presented as numbers with percentages. Categorical data were analyzed with the independent χ^2 test and Fisher exact test if the expected value was less than 5. Nonnormally distributed continuous data were analyzed using the nonparametric Kruskal-Wallis and Dunn tests. Crude reoperation rates were presented with 95% CIs. $P \leq .05$ was considered significant. Cox proportional hazards regression analyses were used to assess the risks of reoperation after primary Lichtenstein groin, laparoscopic TAPP groin, open ventral, and laparoscopic ventral hernia repairs. The estimates were presented as hazard ratios (HRs) with corresponding 95% CIs, and hernia repairs performed by specialists were used as the reference group. The Cox proportional hazards regression analyses for both Lichtenstein and laparoscopic TAPP repair of primary groin hernia were adjusted for the patient's age,[17] hernia defect size as defined by the European Hernia Society,[18] and the type of inguinal and femoral hernias separately.[19] The Cox proportional hazards regression analysis for open primary umbilical and epigastric hernia repair was adjusted for the patient's age,[20] body mass index (BMI),[21] smoking status,[21] transverse hernia defect size,[21] and the use of mesh vs no mesh.[22] In the laparoscopic primary ventral hernia repair group, there were 21 reoperations, and in Cox regressions approximately 10 events should be present per included covariate.[23] Therefore, the covariates included in the analysis of this group were chosen theory based, and the Cox regression in the laparoscopic primary ventral hernia repair group was adjusted for defect closure[24] in addition to supervised residents vs specialists. Kaplan-Meier plots were used to depict the unadjusted cumulative reoperation rate after hernia repairs performed by supervised residents and specialists, and the log-rank test was used to determine statistical significance.

Results

Patient and Operative Characteristics for Included Hernias

A total of 868 specialists and residents who performed 31 683 primary groin and 7777 primary ventral hernia repairs were included in this study. A flowchart of the inclusion process is depicted in **Figure 1**.

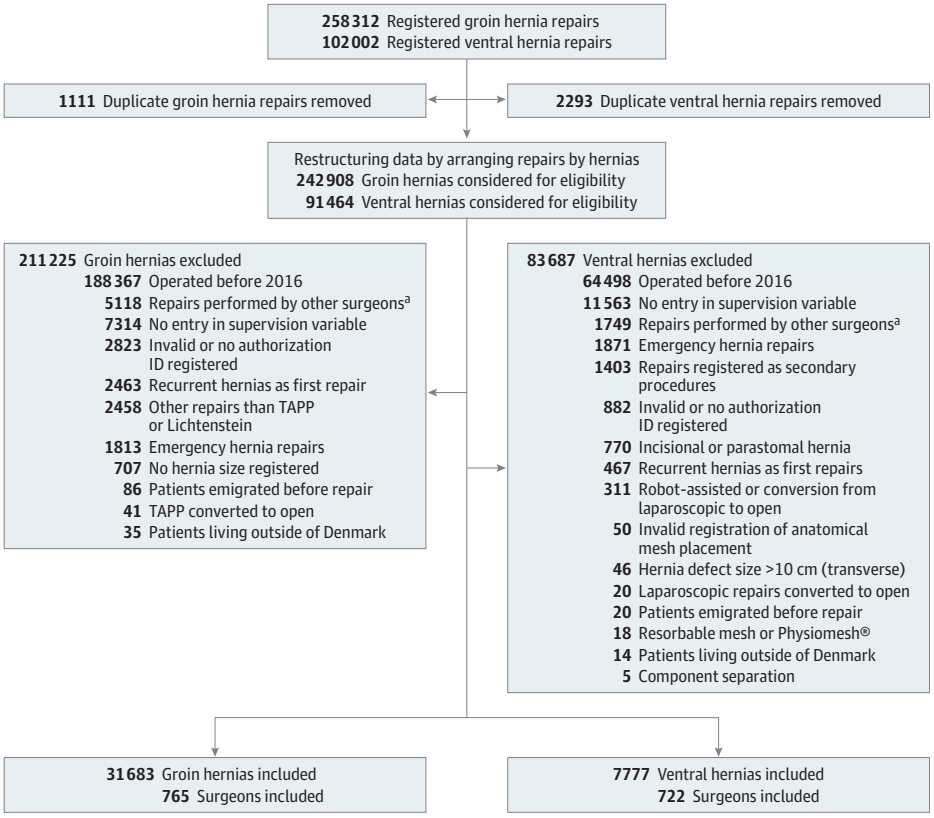
The median age of patients who underwent hernia repair was 60 years (IQR, 48-70 years), 33 424 patients (84.7%) were male, and 6036 (15.3%) were female. Other patient characteristics and demographics of the included hernia repairs are given in **Table 1**. Supervised residents performed the laparoscopic hernia repairs significantly later in their residency compared with the open approaches. The median time from residents' graduation until supervised Lichtenstein groin hernia repair was 4 years (IQR, 2-6 years) and 7 years (IQR, 4-9 years) until laparoscopic TAPP primary groin hernia repair ($P < .001$). For supervised open primary ventral hernia repair, the median time from residents' graduation was 3 years (IQR, 2-5 years), while for supervised laparoscopic primary ventral hernia repairs the median time from graduation was 6 years (IQR, 4-8 years) ($P < .001$). Furthermore, only 7.7% of the laparoscopic groin and 7.6% of the laparoscopic ventral hernia repairs were performed by supervised residents.

Outcomes

The total crude reoperation rates after primary Lichtenstein groin (2.9; 95% CI, 2.6-3.2), laparoscopic TAPP groin (2.5; 95% CI, 2.3-2.7), open ventral (2.0; 95% CI, 1.7-2.4), and laparoscopic ventral (1.3; 95% CI, 0.8-1.9) hernia repairs are provided in **Table 2**. There was no difference in the crude reoperation rates after primary hernia repairs performed by supervised residents compared with specialists in the 4 groups.

Results of the adjusted Cox proportional hazards regression analyses for risk of recurrence-related reoperation after primary Lichtenstein groin, laparoscopic TAPP groin, open ventral, and laparoscopic ventral hernia repairs are given in **Table 3**. The adjusted analyses for risk of reoperation with the included covariates are presented in the eTable in the Supplement. According to the adjusted analyses, there were no significant differences in the risk of reoperation due to recurrence after primary hernia repairs performed by supervised residents compared with specialists for primary Lich-

Figure 1. Flowchart of Included Hernias and Surgeons



TAPP indicates transabdominal preperitoneal laparoscopic repair; ventral includes umbilical and epigastric hernias.

[a] Unsupervised residents or supervised specialists.

tenstein groin, laparoscopic TAPP groin, open ventral, or laparoscopic ventral hernias. The unadjusted cumulative recurrence-related reoperation rate is depicted in the Kaplan-Meier plots in **Figure 2**. There was no significant difference in the adjusted risk of reoperation after Lichtenstein groin hernia repair (HR, 1.26; 95% CI, 0.99-1.59), laparoscopic groin hernia repair (HR, 1.01; 95% CI, 0.73-1.40), open ventral hernia repair (HR, 0.89; 95% CI, 0.61-1.29), and laparoscopic ventral hernia repair (HR, 2.96; 95% CI, 0.99-8.84) performed by supervised residents compared with those by specialists. There was a slightly increased cumulative reoperation rate after Lichtenstein repair of primary groin hernias performed by supervised residents compared with specialists. After 5 years, the cumulative reoperation rate after Lichtenstein repairs performed by supervised residents was 4.8% compared with 4.2% for repairs performed by specialists (P = .048). There was no difference in the cumulative reoperation rates after primary laparoscopic TAPP groin, open ventral, and laparoscopic ventral hernia repairs performed by supervised residents compared with those by specialists.

We excluded all laparoscopic repairs converted to an open approach. There were 41 laparoscopic TAPP primary groin hernia repairs converted to an open approach; of these, 1 was performed by a supervised resident while 40 were performed by specialists, this difference was not significant (P = .37). There were 28 laparoscopic primary ventral hernia repairs converted to open approach; of these, 2 were performed by supervised residents while 18 were performed by specialists (P = .66).

Discussion

According to our findings, primary hernia repairs performed by supervised residents did not appear to be associated with higher risk of reoperation for recurrence. Furthermore, there was no difference in the conversion rates from the laparoscopic to open approach for both primary groin and ventral hernia repairs for supervised residents compared with specialists. These findings are reassuring since hernia repair is a part of the surgical training curriculum in many countries.

General surgery training programs vary from country to country,[25] and the minimum number of hernia repairs required during residency varies from 80 repairs of groin and ventral hernias in the US[26] and 50 inguinal hernia repairs in the UK,[27] to 20 competency-evaluated groin and ventral hernia repairs in Denmark.[28] Of these repairs, the majority are probably performed as supervised operations. In reality, the number of hernia repairs performed by residents varies across the world[29]; with the increasing complexity of abdominal surgery, residents do not necessarily become fully familiarized with laparoscopic hernia repair before becoming a specialist in general surgery.[30] In addition, we found that residents encountered laparoscopic hernia repair techniques significantly

Table 1. Patient and Operative Characteristics for the Included Hernias

Characteristic	No. (%)		
		Hernia repairs performed by	
	Total	Supervised residents	Specialists
Lichtenstein groin hernia	10 140 (100)	3567 (35.2)	6573 (64.8)
Age, median (IQR), y	69 (59-75)	69 (59-75)	69 (59-75)
Sex			
Male	9998 (98.6)	3540 (99.2)	6458 (98.3)
Female	142 (1.4%)	27 (0.8%)	115 (1.7%)
Defect size[a]			
EHS 1	784 (7.7)	209 (5.9)	575 (8.7)
EHS 2	4986 (49.2)	1876 (52.6)	3110 (47.3)
EHS ≥3	4370 (43.1)	1482 (41.5)	2888 (43.9)
Type of hernia			
Inguinal	10 110 (99.7)	3556 (99.7)	6554 (99.7)
Femoral	1 (0.01)	1 (0.02)	0
Combination	29 (0.3)	10 (0.3)	19 (0.3)
Laparoscopic TAPP groin hernia	21 543 (100)	1658 (7.7)	19 885 (92.3)
Age, median (IQR), y	58 (47-69)	60 (49-70)	58 (47-69)
Sex			
Male	18 331 (85.1)	1343 (81.0)	16 988 (85.4)
Female	3212 (14.9)	315 (19.0)	2897 (14.6)
Defect size[a]			
EHS 1	2406 (11.2)	211 (12.7)	2195 (11.0)
EHS 2	11 269 (52.3)	879 (53.0)	10 390 (52.3)
EHS ≥3	7868 (36.5)	568 (34.3)	7300 (36.7)
Type of hernia			
Inguinal	20 278 (94.1)	1536 (92.6)	18 742 (94.3)
Femoral	852 (4.0)	76 (4.6)	776 (3.9)
Combination	413 (1.9)	46 (2.8)	367 (1.8)
Open ventral hernia[b]	6136 (100)	2151 (35.1)	3985 (64.9)
Age, median (IQR), y	50 (40-61)	50 (39-61)	50 (40-61)
Sex			
Male	3958 (64.5)	1380 (64.2)	2578 (64.7)
Female	2178 (35.5)	771 (35.8)	1407 (35.3)
BMI >30	1045 (17.0)	384 (17.9)	661 (16.6)
Smoking status			
Active	721 (11.8)	286 (13.3)	435 (10.9)
Unknown	2086 (34.0)	751 (34.9)	1335 (33.5)
Defect size, median (IQR), cm	1 (1-2)	1 (0.8-1.6)	1 (1-2)
Type of hernia			
Umbilical	4754 (77.5)	1678 (78.0)	3076 (77.2)
Epigastric	1382 (22.5)	473 (22.0)	909 (22.8)
Use of mesh			
Mesh	4283 (69.8)	1543 (71.7)	2740 (68.8)
No mesh	1853 (30.2)	608 (28.3)	1245 (31.2)
Laparoscopic ventral hernia[b]	1641 (100)	124 (7.6)	1517 (92.4)
Age, median (IQR), y	54 (46-62)	56 (48-65)	54 (46-62)
Sex			
Male	1137 (69.3)	88 (71.0)	1049 (69.1)
Female	504 (30.7)	36 (29.0)	468 (30.9)

(continued)

Table 1. Patient and Operative Characteristics for the Included Hernias (continued)

Characteristic	No. (%)		
		Hernia repairs performed by	
	Total	Supervised residents	Specialists
BMI >30	541 (33.0)	46 (37.1)	495 (32.6)
Smoking status			
Active	170 (10.4)	17 (13.7)	153 (10.1)
Unknown	523 (31.9)	52 (41.9)	471 (31.0)
Defect size, median (IQR), cm	2 (2-3)	2.5 (2-3)	2 (2-3)
Type of hernia			
Umbilical	1299 (79.2)	93 (75.0)	1206 (79.5)
Epigastric	342 (20.8)	31 (25.0)	311 (20.5)
Defect closure	979 (59.7)	91 (73.4)	888 (58.5)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); EHS, European Hernia Society; TAPP, transabdominal preperitoneal.

[a] Defect sizes were classified according to the EHS classification[18] as follows: EHS1 indicates defect size under 1 finger width (<1.5 cm); EHS2, defect size 1 to 2 fingers (<3 cm); and EHS of 3 or greater, defect size more than 3 fingers (>3 cm).

[b] Ventral hernias include primary umbilical and epigastric hernias.

Table 2. Crude Reoperation Rates and Follow-up for Recurrence Reported for Supervised Residents and Specialists

Type of hernia and repair	Total	Supervised residents	Specialists
Groin hernia			
Lichtenstein			
Reoperation rate, % (95% CI)	2.9 (2.6-3.2)	3.3 (2.7-3.9)	2.6 (2.3-3.1)
Follow-up, median (IQR), mo	33 (15-48)	32 (15-47)	33 (16-48)
Laparoscopic TAPP			
Reoperation rate, % (95% CI)	2.5 (2.3-2.7)	2.4 (1.8-3.2)	2.5 (2.3-2.7)
Follow-up, median (IQR), mo	29 (13-46)	29 (12-45)	29 (13-46)
Ventral hernia[a]			
Open			
Reoperation rate, % (95% CI)	2.0 (1.7-2.4)	1.9 (1.4-2.6)	2.1 (1.7-2.6)
Follow-up, median (IQR), mo	31 (16-47)	34 (19-47)	30 (14-47)
Laparoscopic			
Reoperation rate, % (95% CI)	1.3 (0.8-1.9)	3.2 (1.1-7.5)	1.1 (0.7-1.7)
Follow-up, median (IQR), mo	36 (21-48)	40 (24-51)	36 (20-48)

Abbreviation: TAPP, transabdominal preperitoneal.

[a] Ventral hernias include umbilical and epigastric hernias.

later during residency compared with open techniques for both groin and ventral hernia repairs, underlining the importance of supervision. Furthermore, only 7.7% of laparoscopic groin and 7.6% of laparoscopic ventral hernia repairs were performed by supervised residents (Table 1), reflecting that the number of laparoscopic hernia repairs available to residents might be limited in our population. This is worrying since the use of laparoscopic technique is increasing while the use of open techniques is decreasing.[31,32]

The adjusted analyses for risk of reoperation showed no significant changes in risks of reoperation after primary Lichtenstein groin, laparoscopic TAPP groin, open ventral, and laparoscopic ventral hernia repairs. The analyses were adjusted for competing factors that could potentially affect the risk of reoperation. In addition, it is important to underline that the adjusted analyses take these competing factors into account, making the estimated risks more accurate. After laparoscopic ventral hernia repair performed by supervised residents, the risk of reoperation was 2.96 (95% CI, 0.99-8.84). Although this was not statistically significant, this seemingly increased risk might have clinical implications.

The unadjusted cumulative reoperation rate after Lichtenstein repair of primary groin hernias showed a slight difference of 0.6 percentage points between supervised residents (4.8%) and specialists (4.2%); thus, not clinically important. A previous observational study[33] confirmed that the recurrence rate did not differ between supervised trainees and consultants after both laparoscopic and open repair of groin hernias. Another observational study[34] showed that laparoscopic TAPP performed by trainees guided by specialists were not associated with a higher risk of recurrence compared with repairs performed by specialists alone, and laparoscopic TAPP groin hernia repair can be performed safely by trainees under supervision, thus supporting our findings. A Swedish register-based study[35] found an increased risk of reoperation after Lichtenstein repair of primary inguinal hernias performed by supervised as well as unsupervised trainees compared with specialists. The risk of reoperation, presented as HRs, ranged from 1.60 (95% CI, 1.18-2.17) to 1.72 (95% CI, 1.25-2.37) for unsupervised trainees, depending on their operation time, and an HR of 1.55 (95% CI, 1.05-2.27) for supervised trainees.[35] This is not a sign that trainees should be excluded from Lichtenstein hernia repairs but rather a sign that in some settings there might still be a need to focus on training and adequate supervision.[35]

Strengths and Limitations

This study has several strengths. The study period was defined by when the supervision variable became a required entry in the Danish Hernia Databases in 2016. There were some registrations in the supervision variable before 2016; however, these were excluded to minimize risk of bias. The follow-up in the Danish Hernia Databases is approximately 100%, since they also include data from the Danish National Patient Registry[13] and Civil Registration System[14]; thus, there were no losses to follow-up in our population, since patients who died or emigrated during the study period were censored in our analyses. Open and laparoscopic approaches were analyzed separately, as were primary groin and primary ventral hernia repairs, since the anatomy, techniques used, and learning curves vary depending on the type of hernia and operative approach.[4-7] Furthermore, we included only elective hernia repairs, since there was probably more time for adequate supervision during elective repairs than during emergency repairs and emergency abdominal repairs are usually more complex.[30]

However, there are also limitations to this study. The supervision variable in the Danish Hernia Databases is dichotomous (yes or no), and it contains no information on the level of supervision or the supervising surgeon. It was possible to adjust for BMI and smoking status in the analysis of primary ventral hernia

Table 3. Risk of Reoperation Assessed With Cox Proportional Hazards Regression Analyses for Operations Performed by Supervised Residents vs Specialists

Type of hernia and repair	Hazard ratio (95% CI)	*P* value
Groin hernia		
Lichtenstein[a]		
Supervised residents	1.26 (0.99-1.59)	.06
Specialists	1 [Reference]	
Laparoscopic TAPP[a]		
Supervised residents	1.01 (0.73-1.40)	.95
Specialists	1 [Reference]	
Ventral hernia[b]		
Open[c]		
Supervised residents	0.89 (0.61-1.29)	.54
Specialists	1 [Reference]	
Laparoscopic[d]		
Supervised residents	2.96 (0.99-8.84)	.052
Specialists	1 [Reference]	

Abbreviation: TAPP, transabdominal preperitoneal laparoscopic repair.

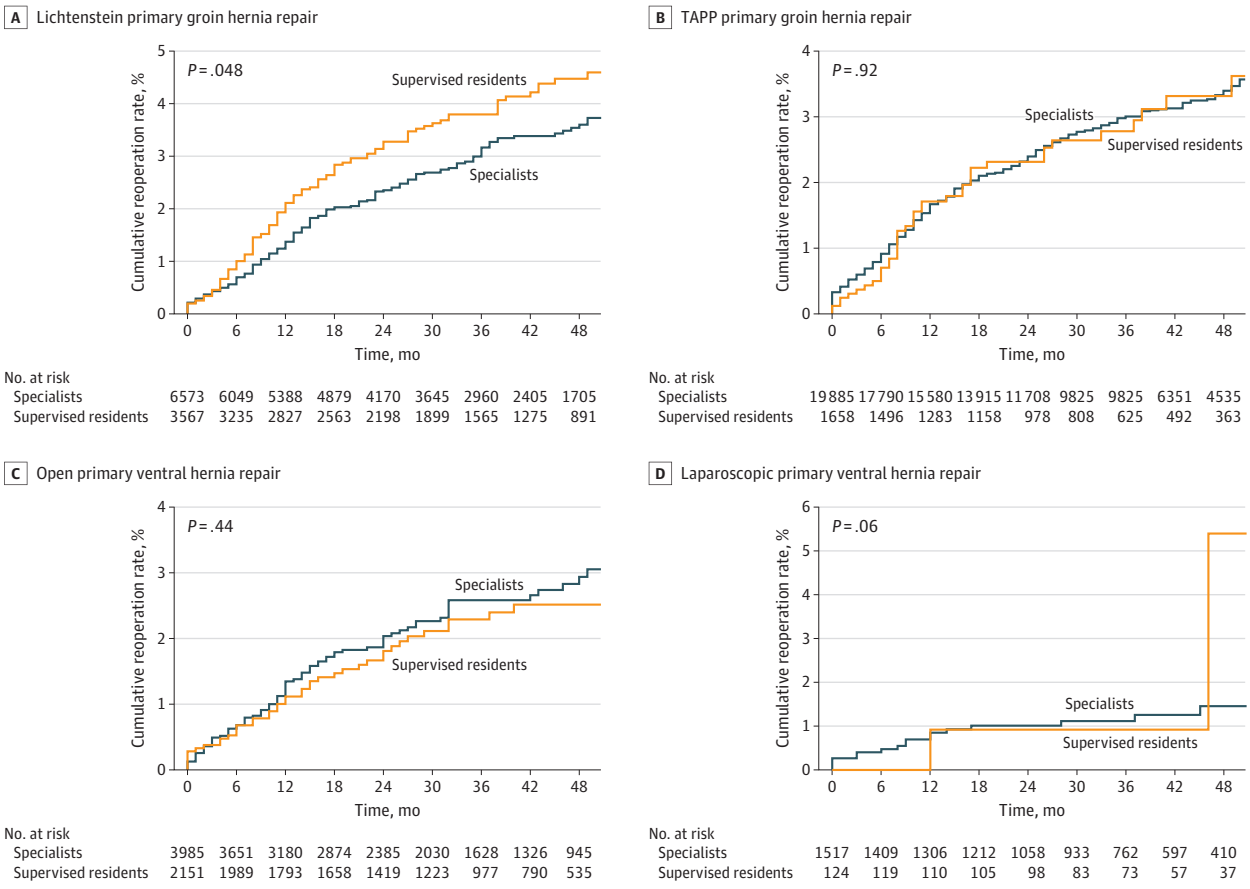
[a] Adjusted for age, type of hernia, and size.

[b] Ventral hernias include umbilical and epigastric hernias.

[c] Adjusted for age, body mass index, smoking status, hernia size, and use of mesh.

[d] Adjusted for defect closure.

Figure 2. Kaplan-Meier Plots Showing the Cumulative Recurrence-Related Reoperation Rate Among Supervised Residents and Specialists



Graphs show the number of hernia repairs at risk for reoperation over time. TAPP indicates transabdominal preperitoneal laparoscopic repair.

repairs. However, data on BMI and smoking status were not available in the Danish Inguinal Hernia Database and were therefore not included in the analyses of primary groin hernia repairs, although both have been associated with a higher risk of recurrence.[19] The numbers of laparoscopic groin and ventral hernia repairs performed by supervised residents were only 7.7% and 7.6%, respectively, due to a limitation of elective laparoscopic hernia repairs available to residents in the current study setting. This resulted in a wide 95% CI especially for laparoscopic ventral hernia repairs performed by supervised residents; therefore, a statistical type II error cannot be ruled out. Thus, further research in larger study settings is needed, with a larger population of surgeons and patients, investigating whether residents can safely perform laparoscopic hernia repairs.

Conclusions

The findings of this cohort study suggest that elective open and laparoscopic repair of primary groin, umbilical, and epigastric hernias performed by supervised residents may have a similar risk of reoperation for recurrence as operations by specialists. Thus, a supervised resident is unlikely to be a risk factor for recurrence-related reoperation. Supervised residents can safely perform elective hernia repairs with acceptable outcomes for patients, and elective hernia repair can be managed safely as part of the surgical training curriculum when residents are supervised.

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Supplementary Online Content

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eTable. Risk of Reoperation Assessed With Cox Proportional Hazard Analyses for Supervised Residents, Using Specialists as Reference

This supplementary material has been provided by the authors to give readers additional information about their work.

eTable. Risk of Reoperation Assessed With Cox Proportional Hazard Analyses for Supervised Residents, Using Specialists as Reference

	Hazard ratio	95% CI	*p* value
Groin hernia			
Lichtenstein			
Repair performed by			
Supervised resident	1.26	0.99–1.59	0.057
Specialist	1		
Age, years	1.00	0.99–1.01	0.588
Hernia size			
EHS 1	1		
EHS 2	1.09	0.65–1.91	0.747
EHS ≥3	1.34	0.82–2.32	0.230
Type of hernia			
Lateral	1		
Medial	2.66	2.06–3.45	<0.0001
Pantaloon	1.61	1.05–2.48	0.029
Laparoscopic TAPP			
Repair performed by			
Supervised resident	1.01	0.73–1.40	0.951
Specialist	1		
Age, years	1.00	0.99–1.01	0.710
Hernia size			
EHS 1	1		
EHS 2	0.89	0.66–1.20	0.433
EHS ≥3	1.68	1.23–2.29	0.001
Type of hernia			
Lateral (inguinal)	1		
Medial (inguinal)	0.86	0.71–1.03	0.101
Pantaloon (inguinal)	0.94	0.65–1.36	0.743
Femoral	0.28	0.12–0.63	0.002
Ventral hernia			
Open			
Repair performed by			
Supervised resident	0.89	0.61–1.29	0.540
Specialist	1		
Age, years	0.99	0.98–1.01	0.259
BMI kg/m^2			
≤30	1		
>30	1.12	0.67–1.88	0.667
Smoking status			
Active	0.48	0.19–1.22	0.123
Non-active	1		
Mesh used			
No	1		
Yes	0.52	0.36–0.76	0.001
Hernia defect size, cm	0.98	0.81–1.18	0.819
Laparoscopic			
Repairs performed by			
Supervised resident	2.96	0.99–8.84	0.052
Specialist	1		
Defect closure			
Yes	1		
No	2.21	0.91–5.37	0.081

BMI: Body Mass Index; CI: confidence interval; EHS: European Hernia Society Classification.[18] TAPP; TransAbdominal PrePeritoneal laparoscopic repair; ventral: includes umbilical and epigastric hernias.