Death following surgery among patients with long-term disease: Prospective study of routinely collected data in the English NHS.

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Abstract

Background

Five million surgeries take place in the National Health Service (NHS) each year. Little is known about the prevalence of long-term diseases among these patients, and the association with post-operative outcomes.

Methods

Analysis of routine data from all NHS hospitals in England including patients aged ≥18 years undergoing non-obstetric surgery between 1st January 2010 and 31st December 2015. The primary outcome was death within 90 days after surgery. For each long-term disease, we adjusted for age, sex, presence of other diseases, emergency surgery and year using logistic regression models. We defined high-risk diseases as those with an adjusted odds ratio for death ≥2 and report associated two-year survival.

Results

We included 8,624,611 patients (median age 53 [36-68] years), of whom 6,913,451 (80.2%) underwent elective surgery and 1,711,160 (19.8%) emergency surgery. Overall, 2,311,600 (26.8%) patients had a long-term disease, of whom 109,686 (4.7%) died within 90 days compared to 24,136 (0.4%) of 6,313,011 without long-term disease. Respiratory disease (1,002,281;11.6%), diabetes (662,706;7.7%) and cancer (310,363;3.6%) were the commonest. Four high-risk diseases accounted for 7.7% of patients but 59.0% of deaths: cancer (37,693 deaths[12.1%];OR 8.3[8.2-8.5]), liver disease (8,638 deaths[10.3%];OR 4.5[4.4-4.7]), cardiac failure (26,604 deaths[12.6%];OR 2.4[2.4-2.5]) and dementia (19,912 deaths[17.9%];OR 2.0[1.9-2.0]). Two-year survival was 67.7% among patients with high-risk disease, compared to 97.1% without.

Conclusion

One in four surgical patients have a long-term disease with an associated ten-fold increase in risk of post-operative death. Two thirds of all deaths after surgery occur among patients with high-risk diseases (cancer, cardiac failure, liver disease, dementia).

Introduction

More than 5 million surgical procedures are performed in the UK National Health Service (NHS) each year, with 49,000 deaths within 30 days after surgery.[1] In 1987, the National Confidential Enquiry into Perioperative Death (NCEPOD) report noted that most deaths after surgery occurred amongst elderly patients with existing diseases who had a major procedure.[2] Subsequent work identified around 250,000 patients within the overall surgical population of 5 million that accounted for four out of five deaths after surgery.[3] One way to identify potentially high-risk patients is to select those undergoing (major) procedures that have a risk of death of one in twenty (5%)[4] but this overlooks considerable variation between patients.[5,6–8]

While there have been detailed descriptions of the characteristics of patients undergoing certain types of surgery, the association between specific long-term diseases, age and short-term survival after surgery is unclear in the wider surgical population.[4 14 16 17] In addition, the average age of the surgical population is increasing more rapidly than the age of the general population.[9] Advancing age is associated with the development of long-term diseases known to affect surgical risk, such as heart failure and chronic kidney disease.[10] There have been no recent studies examining how long-term diseases may be affecting surgical outcomes in the context of an aging surgical population. Prior reports have produced conflicting reports of the prevalence of long-term diseases amongst patients undergoing surgery,[11–15] perhaps as a result of differences in inclusion criteria.

Identification of patients at high-risk of poor outcome after surgery is important to support shared decision making, to select those who may benefit from enhanced postoperative care, and to select appropriate individuals to randomised trials. Before it is possible to identify high-risk patients, a detailed understanding of the broader surgical population is required, particularly regarding the risks associated with long-term diseases. The aim of this study was to evaluate the association between long-term disease and the risk of death after surgery.

Methods

We used the Hospital Episode Statistics (HES) admitted patient care database for England. A HES record is generated for every episode of care provided in an NHS hospital or paid for by the NHS. An episode of care is defined as a period spent in hospital under the care of a single consultant, and a hospital stay is made up of one or more episodes.[18] HES records include demographic data, diagnostic codes (using the World Health Organisation International Statistical Classification of Diseases and Related Health Problems, 10th revision [ICD-10] codes) and information about procedures including the date on which each was performed (coded using Office for Population Censuses and Survey Classification of Interventions and Procedures version 4 [OPCS-4] codes).[12,13] Each record has a patient pseudonymiser that enables linkage of all episodes of care received by individuals within the NHS in England. We developed a prospective statistical analysis plan (https://doi.org/10.17636/10170698). Data access was approved by NHS Digital's Independent Group Advising on the Release of Data (ref: DARS-NIC-15335-H0D1F-v5.4). We report in line with the STROBE guidelines.

Inclusion criteria

Patients aged ≥18 years who underwent their first surgery (as observed in HES) between 1st January 2010 and 31st December 2015 were eligible. To ensure the cohort included only primary (index) procedures, a washout period was implemented in which any patients who had undergone surgery between 1st January 2005 and 31st December 2009 was excluded.[21] The record describing the first surgical episode is referred to as the 'index hospital record'. Surgery was defined according to a previously published list of OPCS-4 codes that were refined to remove minimally invasive procedures (Supplementary methods & appendix A). All organ donation or retrieval procedures were excluded (OPCS version 4.7: X45 or X46), as were obstetric admissions. Obstetric admissions were excluded because they represent a fundamentally different patient group to the broader surgical population and have a very low rate of all long-term diseases.

Principal variables

Patients were split into two groups (elective and emergency) based on the HES admission method codes. Procedures were grouped using a previously described mapping based on the anatomical location associated with the OPCS code of the index procedure.[22] This mapping considers only the anatomical location associated with the OPCS code, and not any resource or risk implications of the procedure. Age (recorded in whole years) was calculated based on the date of admission. The individual diseases of the Royal College of Surgeons modified Charlson score (RCS-score), with cancer

and metastatic cancer collapsed into a single cancer variable,[23] were identified using the ICD-10 disease codes in a two-year look-back file that contained all HES admitted patient care records occurring in the two years before the index surgical procedure (Supplementary figure S1). The RCS Charlson algorithm used all 24 ICD-10 codes from each record in the two-year look back file and only those codes in diagnosis fields 2 to 24 in the hospital record for the index surgical admission. The RCS Charlson score was developed to describe the co-morbidity burden amongst surgical patients in the NHS and is based on the Charlson score.[7] Acute diagnoses must be recorded in a prior admission to reduce misclassification bias of acute diseases as chronic. Each individual RCS-score disease is assigned a single point, and the sum of all 13 diseases makes up the RCS-score. Ethnicity codes were aggregated to five categories in line with the 2001 census groups.

Outcome measures

The primary outcome measure was death within 90 days after surgery, with date of death obtained from the Office for National Statistics civil registration death dataset. The secondary outcome measures were length of hospital stay recorded in days, and non-elective hospital readmission within one year of index surgery. Length of hospital stay was calculated as the difference between the date of index surgery and the discharge date for that spell (Supplementary figure S1). We report the proportion of patients surviving two years after surgery. We present time to death right censored to the final date of death in the extract (10th December 2018).

Statistical methods

Characteristics of patients were summarised by admission group. Age is reported as mean (with standard deviation) and median (with interquartile range), categorical variables are reported as count (with percentage of total after exclusion of missing data). We removed records with missing or implausible data and report the frequency of these. Primary and secondary outcomes are presented by admission group. Multivariable logistic regression was used to model the relationship between 90-day death after surgery and age, sex, admission group (elective/emergency), all RCS-score diseases, and year of procedure. Age was included as an untransformed continuous variable. We defined high-risk diseases as those with an adjusted odds ratio of ≥2. We present survival curves among patients with and without comorbidity, and for the diseases identified as being associated with the greatest risk of early death, stratified by admission group. We explored variation in the prevalence of long-term diseases between different types of procedures, and associations with subsequent outcomes, in a sensitivity analysis. This analysis was restricted to patients undergoing elective cataract removal, total hip replacement, coronary artery bypass grafting and colorectal resection (appendix B). We

explored if removing long-term diseases that were potentially associated with the index procedure altered the association between each disease and outcomes. For each record, we removed chronic diseases potentially overlapping with the index procedure category. For example, we recorded peripheral vascular disease as absent for all patients undergoing vascular procedures. We present the adjusted odds associated with each disease. No formal sample size calculation was performed for this cohort study of routinely collected data. Statistical tests were two-sided. All analyses were performed using R (R project core team, Vienna, Version 3.6).

Results

We identified the first surgical procedure for 9,222,400 patients undergoing surgery during the study period. We excluded patients who underwent organ donation as their first procedure (3,315; <0.1%), obstetric procedures (584,029, 6.3%); records with missing admission category (1,264; <0.1%), sex (1,040; <0.1%), records with missing (99; <0.1%) or implausible discharge dates (7,557; <0.1%), or implausible date of death (485; <0.1%). This left 8,624,611 patients for analysis (Figure 1). The median age was 53 years (IQR: 36 to 68 years) and 51.3% (4,423,064 of 8,624,611 records) described patients who were women. Surgical procedures were most frequently performed on an elective basis (80.2%; 6,913,451). Lower gastrointestinal procedures were the most common (11.1%; 955,851) (Supplementary table S1). Most patients had no diseases (73.2%; 6,313,011), and 19.7% had one disease (1,698,815). The characteristics of included patients are summarised stratified by admission category in Table 1.

Prevalence of diseases

The three most common diseases were: respiratory disease (11.6%; 1,002,281), diabetes mellitus (7.7%; 662,706) and cancer (3.6%; 310,363) (Figure 2). The prevalence of many long-term diseases increased with age, but this pattern was not universal. The prevalence of cancer and diabetes decreased among patients aged over 75, and the prevalence of respiratory disease was least among patients aged 35-40 (Supplementary figure S2). The prevalence of all diseases was higher amongst patients undergoing emergency surgery, particularly cardiac failure, dementia, and stroke (Supplementary figure S3). One in fourteen patients had more than one disease (7.1%; 612,785; Supplementary table S2). The proportion of patients with at least one disease increased over the study period (Supplementary table S3).

Outcomes

The overall proportion of deaths within 90 days of surgery was 1.6% (133,822 deaths). Emergency procedures were associated with the highest rate of death within 90 days after surgery (5.7%, 98,001 of 1,711,160). The median length of stay was 0 days (IQR: 0 to 1 days), 39.3% (3,388,333) of patients had a length of stay of one or more days, and the rate of one-year emergency hospital readmission was 7.6% (653,305). The rate of two-year survival after surgery was 94.8% (8,177,319 survivors) (Table 2). The rate of 90-day death reduced over the study period from 1.7% to 1.4% (Supplementary table S3).

Relationship between long-term diseases and outcomes after elective or emergency surgery

Overall, patients with no identified diseases had a very low risk of death within 90 days of surgery (0.4%; 24,163 deaths). Patients with one or more long-term diseases had a risk of death of 4.7% within 90 days of surgery (109,686 deaths). Patients with more than one disease had a risk of death within 90 days of surgery of 10.2% (62,660 of 612,785). This risk of death remained elevated beyond the immediate study period (figure 3). Among patients with no long-term diseases, 6,192,776 (98.1%) survived to two years, compared to 1,984,8543 patients (85.9%) with one or more long-term diseases. As a proportion of all deaths, patients with one or more long-term diseases accounted for 81.9% of all deaths within 90 days of surgery (109,686 of 133,822 deaths).

The four diseases associated with the greatest absolute risk of death after surgery were dementia (19,912 of 111,495 patients died; 17.9%), cancer (37,691 of 310,363 patients died; 12.1%), cardiac failure (26,604 of 210,418 patients died; 12.6%) and stroke (16,492 of 154,363 patients died; 10.7%). These conditions were also associated with the lowest rates of two-year survival (Table 3).

After adjustment for patient age, sex, admission category, and year of procedure, the odds of death within 90 days after surgery increased with all diseases aside from myocardial infarction (OR 1.0 95%CI: 1.0 to 1.0) (Table 3, Supplementary table S7). Four diseases were associated with more than double the odds of death within 90 days: cancer (OR 8.3 [8.2 to 8.5]), liver disease (OR 4.5, 95%CI: 4.4 to 4.6), Cardiac failure (OR 2.4 [2.4 to 2.5]), and dementia (OR 2.0 [1.9 to 2]). Patients with one or more of these high-risk diseases accounted for 7.7% of patients (663,500 of 8,624,611 patients) and 59.0% (78,976 of 133,822) of all deaths within 90 days of surgery. The overall rate of death within 90 days of surgery among patients with one or more high-risk diseases was 11.9% (78,976 deaths). The rate of two-year survival among patients with one or more high-risk diseases was 67.7% (449,089 survivors). These diseases were associated with reduced long-term survival (Supplementary figure S4).

The marginal risk of death at 90 days after adjustment for individuals of different ages with a specific long-term disease, compared with individuals with no disease is shown in supplementary figure S5 for elective procedures. It shows that the absolute risk for patients with no diseases remains low for individuals aged under 90 years (<2%), and the absolute increase in risk is small for some diseases (e.g. diabetes). A similar pattern can be seen for emergency procedures (Supplementary figure S6), although the absolute risk for patients with no diseases is higher and increases more rapidly for

individuals aged over 80 years. The most common procedures performed amongst those with different diseases are in supplementary table S4. The incidence of emergency hospital readmission within one-year of index surgery was substantially increased amongst patients with any disease. The highest rate of emergency hospital readmission was observed amongst patients suffering from dementia (25,942 of 111,495; 23.3% vs all patients 653,305 of 8,624,611; 7.6%) (Supplementary table S5). Patients with dementia had the highest median length of stay (6 days [IQR 1:18 days] vs. all patients 0 days [IQR 0:2 days]) (Supplementary table S6).

Sensitivity analyses

The patterns of long-term diseases varied amongst those undergoing coronary artery bypass grafting, total hip replacement, bowel resection and cataract replacement (Supplementary tables S8-S9). The association between these diseases and outcomes in each setting was different (Supplementary tables S10-S12). Cardiac failure, dementia and liver disease were associated with the greatest risk of death. When we excluded diseases potentially associated with the indication for surgery, our findings were unchanged with the highest adjusted risk of death among patients with cancer (OR 5.9 [5.7 to 6]), liver disease (OR 5.3 [5.2 to 5.5]) and congestive cardiac failure (OR 2.6 [2.5-2.6]). A summary of the logistic regression model is in supplementary table page 13. A full description of the sensitivity analysis is in the supplementary results.

Discussion

Our primary finding was that one quarter of surgical patients in the English NHS had at least one long-term disease. Patients at least one long-term diseases have a tenfold higher risk of death than those without a long-term disease. The prevalence of all diseases, and association between them and death was greater among patients requiring emergency surgery. Four diseases (cancer, cardiac failure, liver disease and dementia) were associated with a greatly increased rate of death, a finding which persisted after adjustment. Patients with at least one of these diseases account for one in thirteen patients, but two thirds of all deaths within ninety days of surgery. One third of these patients die within two years of surgery. Patients without any long-term diseases had a low rate of postoperative death, including patients aged over 80 years.

The prevalence of the selected long-term diseases in this cohort of surgical patients are comparable with those described in prior observational studies of unselected surgical cohort.[26] The prevalence of certain diseases (such as dementia, long-term kidney disease and cardiac failure) increased with age, while others peaked among patients aged in their 70s (such as cancer, diabetes mellitus and respiratory disease). These different patterns have various interpretations. First, it might reflect the number of people alive at given ages with a specific disease. This might explain why the prevalence of diseases like cancer might peak and decline, even though the incidence of cancer increases with age. Asthma was the commonest respiratory disease, accounting for 70% of respiratory cases we identified, and is a disease affecting people of any age. Other respiratory diseases, like chronic obstructive pulmonary disease typically affect older people. Second, some long-standing diseases are associated with reduced life expectancy and so may be less common among surgical patients than those who remain unaffected. Third, degenerative diseases, such as chronic kidney disease, lead to a gradual increase in prevalence with age. The prevalence of dementia was much higher among emergency than elective patients, which may reflect the influence of this diagnosis on selection for elective surgery. For example, patients with advanced dementia may be offered emergency surgery (such as a hip fracture repair) but not elective procedures. The diseases most strongly associated with an increased risk of 90-day postoperative death were cancer, liver disease, cardiac failure, and dementia. Patients with at least one of these diseases account for two thirds of deaths after surgery. These results are consistent with the findings of prior studies.[6 11 24] Other diseases (e.g. diabetes and rheumatological diseases) were associated with a more modest association with postoperative death. The presence of these diseases resulted in a minimal change to the absolute risk of death among patients who had an elective procedure, and a modest change among those having emergency

surgery. We identified any emergency hospital admission within one year of surgery, these were more common among patients with long-term disease. Diseases associated with the highest risk of hospital admission were dementia, cardiac failure, and stroke. We did not explore the reasons for these hospital admissions as this was outside the scope of this study but this presents an important avenue for future study to determine if certain interventions may prevent need for hospital admission. While the patterns identified in the overall cohort persisted in our sensitivity analyses, the influence of different diseases varies with specific surgical settings, such as the high risk of death associated with liver disease amongst those undergoing coronary artery bypass grafting. The varying prevalence of long-term diseases and associated outcomes we observed between our specified procedures highlight the challenges of exploring this issue in a heterogeneous patient cohort. Including all patients undergoing a range of procedures provides the average effect of each disease across all procedures. Patient and procedure information is required to provide an accurate estimation of risk at a patient level. The aim of our study was not to provide patient level risk estimates, but to explore the prevalence of risk factors, specifically long-term diseases, and their association with risk. The current study provides important baseline knowledge that is required to facilitate a detailed examination of high-risk patient groups. The rate of death associated with all diseases was substantially increased amongst patients requiring emergency surgical procedures. Hip fracture and emergency laparotomy are two settings where potential improvements have been identified and national clinical audits established.[4,15] Our findings suggest that a broader examination of emergency surgical care may be necessary to improve care for this population. The high rate of death after surgery amongst those with dementia, particularly amongst patients needing emergency surgery, is worrying given the increasing age of the surgical population. National approaches to diagnose conditions like dementia earlier may also increase the number of surgical patients diagnosed with dementia, who may have a different risk profile to those with advanced dementia. Strategies to reduce postoperative cognitive dysfunction are the focus of ongoing trials. It is also the topic of the third Sprint National Audit Project in the United Kingdom and will provide a more detailed prospective study of these patients.[31 32]

The planned sensitivity analysis using four elective surgical procedures was undertaken to determine if the observed patterns in the overall surgical cohort persisted for different subgroups. This analysis of patients undergoing coronary artery bypass grafting, colorectal resection, total hip replacement or cataract showed that both the prevalence of long-term diseases and the influence of each one on outcomes varied. Our findings are consistent with the results from other studies using similar surgical cohorts.[7,23] The association between cardiac failure and poor outcomes across all settings reinforces findings of prior prospective cohort studies.[34–36] However, our findings also point to potential areas of

improvement in patient care. There is an overlap between the occurrence of long-term disease, the surgical procedure, and the underlying disease requiring surgery. How these three features interact to promote poor patient outcomes remains poorly understood. In our sensitivity analysis excluding diseases potentially overlapping with the index surgical procedure, cardiac failure, liver disease and cancer remained strongly associated with death, while the influence of dementia was diminished. Similarly, different combinations of long-term diseases will have a variable influence on patient outcomes and this effect is not likely to be simply additive. One in fourteen patients in our study had more than one RCS Charlson disease and a higher risk of death after surgery. The limited number of diseases in the RCS Charlson score probably under-estimates the extent of patients with multiple long-term diseases (multimorbidity) but patients afflicted in this way are reported to be at risk of premature mortality in other settings.[11,12] The lack of a unifying definition of multimorbidity, however, hampers comparisons between settings.[12,14] A detailed examination of multimorbidity was outside the scope of the current study but requires further investigation.

This analysis has various strengths. Firstly, it is a large, population-based study of long-term diseases suffered by surgical patients. It provides a comprehensive overview of an entire national healthcare system over a five-year period and has excellent follow-up by using date of death from the national death register. Secondly, we used a comprehensive approach to map long-term diseases according to the previously published RCS-score, including the use of a look back file to identify previously recorded diagnoses. This analysis also has several limitations. Firstly, we included the first procedure only. A proportion of patients in the cohort will have had further surgical procedures during the study period, and so extrapolating the results to the whole surgical population requires caution. A benefit of including only the first procedure was that it removed the impact of re-operations or revision surgery after the index procedure. Secondly, it is possible some patients did not have their diseases accurately recorded in HES because hospital coders focus on those relevant to the admission. For example, the very low prevalence of Human Immunodeficiency Virus should be interpreted cautiously. However, audits of the quality of HES data, particularly for procedures and diagnoses, show completeness is very high for important comorbid diseases. Thirdly, our estimates of mortality will be affected by emigration from England, but this should lead to an underestimation of deaths, and allows us to present conservative figures. Fourthly, for certain procedures, the indication for procedure and comorbid diseases may overlap (for example, patients requiring coronary artery bypass graft suffering from heart failure). We minimised this by excluding the primary diagnosis code from the index hospital episode record and performed a sensitivity analysis excluding diagnoses where the surgical type and diagnosis overlapped. Our overall findings were unchanged.

Conclusion

Surgical procedures are safe for most patients, with a low risk of death at 90 days. This is particularly the case for patients requiring elective surgery. The presence of long-term diseases is associated with increased death within 90 days of surgery. One in four patients (1.25 million patients annually) presenting for a first surgical procedure have one or more long-term diseases. Certain diseases (cancer, dementia, cardiac failure, and liver disease) are associated with substantially worse outcomes, while others (diabetes mellitus, myocardial infarction, rheumatological diseases) have a more modest impact. Patients with a high-risk long-term disease account for one in thirteen procedures, but two thirds of deaths after surgery. Future research should explore how different long-term diseases interact together, and with specific surgical procedures, to promote poor patient outcomes to develop strategies to improve care, particularly for patients requiring emergency surgical care.

Contributors

AJF, JP, RP & DC were responsible for study design. AF, HW & DC were responsible for data collection and analysis. All authors were responsible for interpretation. AF & DC were responsible for writing the first draft of the manuscript. All authors revised the manuscript for important intellectual content and approved the final version. AJF, HW & DC have access to the data and act as guarantors.

Competing interest statement

AJF holds a National Institute for Health Research Doctoral Research fellowship (DRF-2018-11-ST2-062). MAHW, MS and JP report no relevant conflicts of interest. RP has received honoraria and/or research grants from Edwards Lifesciences, Intersurgical and GlaxoSmithkline within the last five years and holds editorial roles with the British Journal of Anaesthesia and the British Journal of Surgery. TA holds a National Institute for Health Research Clinical Lectureship, is a member of the editorial board of the British Journal of Anaesthesia and has received consultancy fees from MSD within the last 5 years unrelated to this work. DC is an associate editor of the Journal of Health Services Research & Policy.

Transparency declaration

AF affirms the manuscript is an accurate and transparent account of the study being reported. No important aspects of the study have been omitted.

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Data sharing

This study used data derived from Hospital Episode Statistics and the Office for National Statistics. It is not possible to share raw patient-level data without approvals from NHS Digital.

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Patient and public involvement

A patient representative was consulted in the design and interpretation of this study.

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Tables

	All	Elective	Emergency
	8,624,611	6,913,451 (80.2%)	1,711,160 (19.8%)
Age			
Mean (SD)	52.4 (19.6)	52.7 (19)	51.3 (22.2)
Median (IQR)	53 (36 to 68)	53 (38 to 68)	50 (31 to 70)
Sex			
Female	51.4 %	52.8 %	45.6 %
Male	48.7%	47.2%	54.5%
Unspecified	<0.1 %	0.1 %	0.1 %
Ethnicity			
White	76.5%	75.9%	78.7%
Unknown	14.6%	15.5%	10.8%
Asian	4.1%	4%	4.6%
Other	2.6%	2.4%	3.6%
Black	2.2%	2.1%	2.3%
RCS-Score ≥ 1	26.8%	25%	34.1%
RCS-Score diseases			
Respiratory disease	11.6%	11.3%	13%
Diabetes mellitus	7.7%	7.4%	8.7%
Cancer	3.6%	3.5%	4.1%
Cardiac failure	2.4%	1.7%	5.3%
Chronic kidney disease	2.4%	2%	4%
Stroke	1.8%	1.3%	3.9%
Peripheral vascular disease	1.7%	1.3%	3.3%
Myocardial infarction	1.6%	1.5%	2.2%
Rheumatological diseases	1.4%	1.4%	1.6%
Dementia	1.3%	0.5%	4.4%
Liver disease	1%	0.7%	1.9%
Paraplegia	0.4%	0.3%	1%
Human immunodeficiency virus	<0.1%	<0.1%	<0.1%

Table 1. Characteristics of included patients undergoing surgery divided by admission category, RCS-Score; Royal College of Surgeons score; SD, standard deviation; IQR, interquartile range. Data presented as % of total unless otherwise stated. Admission category based on admission method and patient class. Ethnicity is reported as five categories to align with the 2001 census categories; 'Asian' refers to South Asian groups, participants recorded as Chinese are included in the 'Other' ethnic group.

	Number of patients	90-day death	Readmission within 1 year	Length of hospital stay		Proportion surviving to two years
				Median (IQR) days	% with >0 day stay	
All						
All patients	8,624,611	1.6%	7.6%	0 (0 to 1)	39.3%	94.8%
Admission category						
Elective	6,913,451	0.5%	6.5%	0 (0 to 1)	29.0%	96.6%
Emergency	1,711,160	5.7%	12.1%	2 (1 to 6)	81.0%	87.5%
Long term disease						
Present	2,311,600	4.7%	14.1%	1 (0 to 4)	53.7%	85.9%
Absent	6,313,011	0.4%	5.2%	0 (0 to 1)	34%	98.1%

Table 2. Outcomes after surgery, divided by admission category of index surgical procedure. Death data from linkage to Office for National Statistics civil registration data. Readmission within one year determined from hospital episode statistics admitted patient care and includes any emergency admission within 365 days of index surgical procedure.

Disease	Number	Prevalence	Proportion dying within 90 days	Adjusted odds ratio for death at 90 days (95%CI)	Proportion surviving to two years
Respiratory disease	1,002,281	11.6%	3.5%	1.6 (1.6 to 1.7)	89.6%
Diabetes mellitus	662,706	7.7%	3.5%	1.1 (1.1 to 1.1)	88.2%
Cancer	310,363	3.6%	12.1%	8.3 (8.2 to 8.5)	64.4%
Cardiac failure	210,418	2.4%	12.6%	2.4 (2.4 to 2.5)	70.6%
Chronic kidney disease	208,735	2.4%	9.7%	1.5 (1.4 to 1.5)	73.5%
Stroke	154,363	1.8%	10.7%	1.6 (1.6 to 1.6)	72.7%
Peripheral vascular disease	146,012	1.7%	9.0%	1.9 (1.9 to 2)	77.7%
Myocardial infarction	141,043	1.6%	5.7%	1 (1 to 1.1)	82.7%
Rheumatological diseases	121,590	1.4%	3.8%	1.1 (1.1 to 1.1)	87.2%
Dementia	111,495	1.3%	17.9%	2 (1.9 to 2)	52.9%
Liver disease	83,740	1.0%	10.3%	4.5 (4.4 to 4.6)	76.9%
Hemiplegia or paraplegia	37,518	0.4%	8.2%	1.2 (1.1 to 1.2)	76.7%
HIV	41	<0.1%	<0.1%	0 (0 to >20)	>90%*

Table 3. Proportion of patients suffering each disease, crude proportion of patients dying within 90 days and adjusted odds ratio for death. Odds ratios adjusted for age, sex, year of procedure, admission category and presence of other diseases. HIV; Human immunodeficiency virus. * Numbers changed to s

Figure legends:

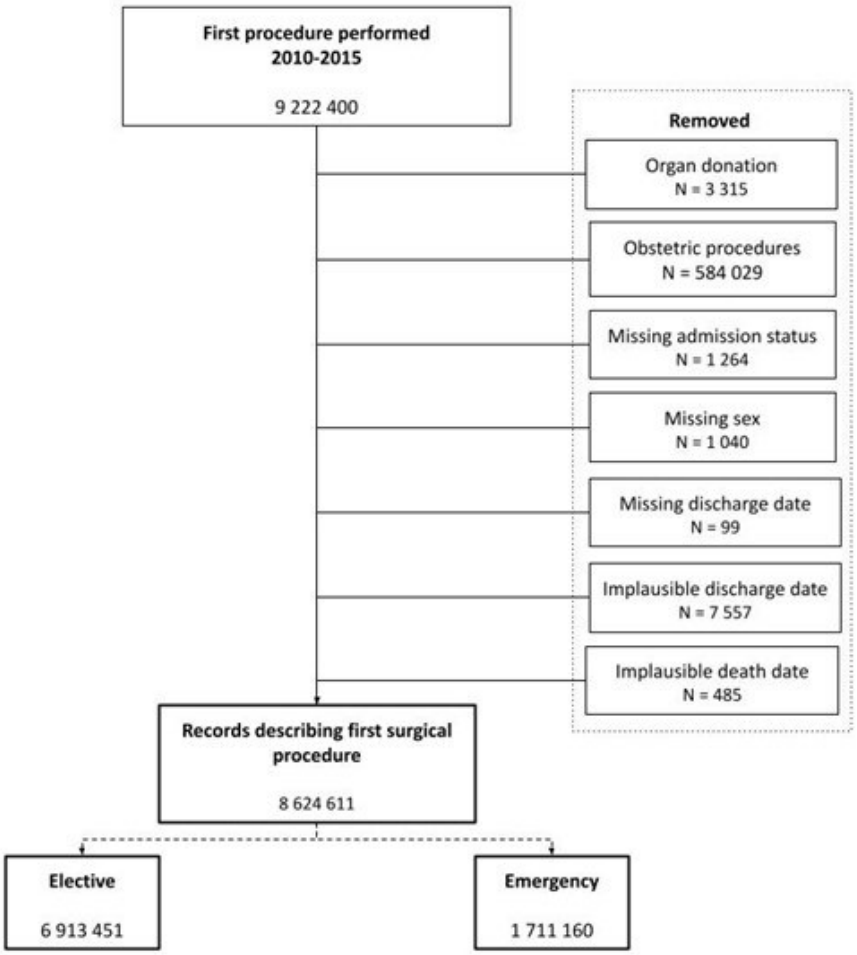

Figure 1. Flow diagram of patient selection. Reasons for exclusion are provided on the right-hand side and final study population includes those undergoing a surgical procedure meeting a previously described definition of surgery.

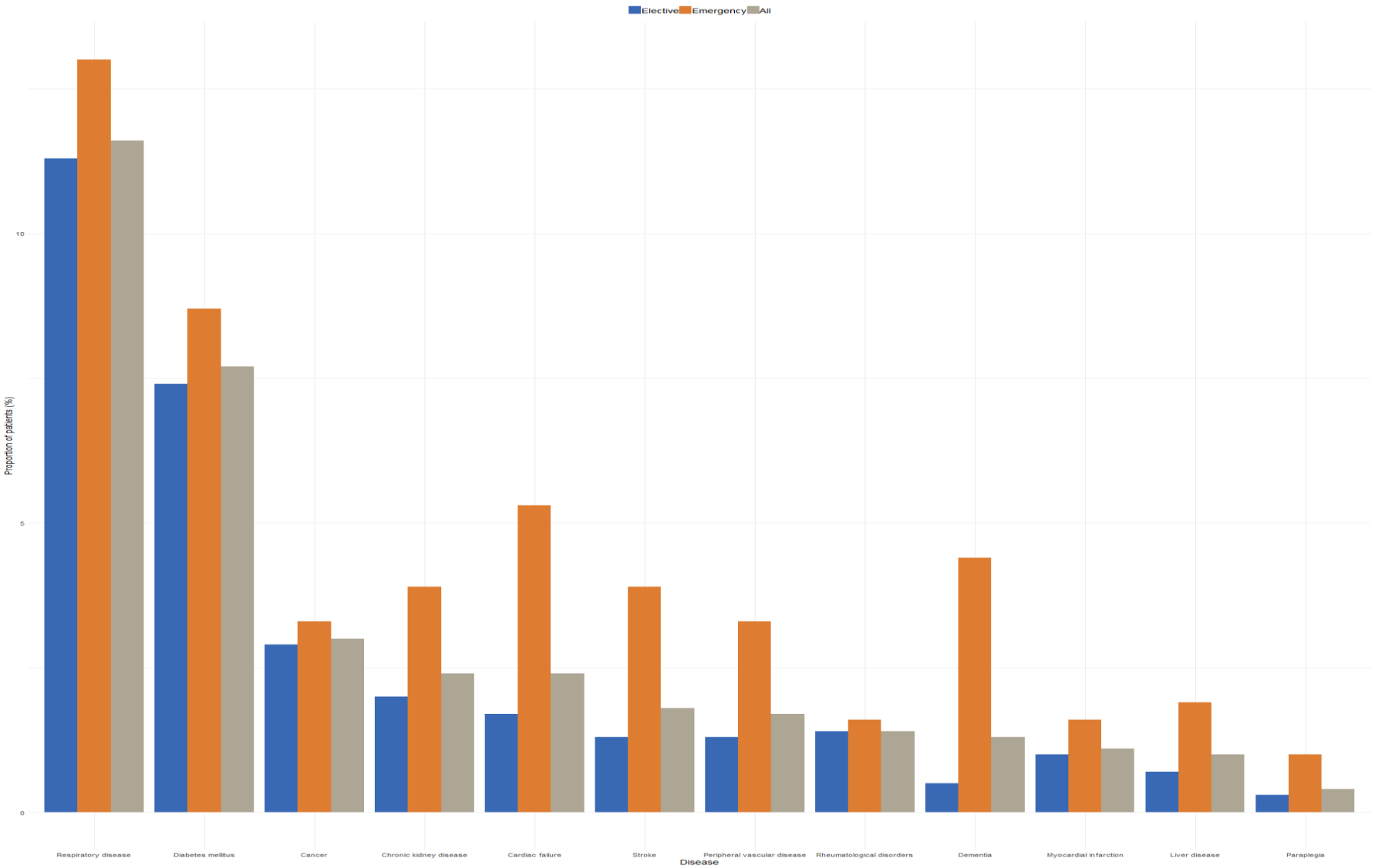

Figure 2. Prevalence of each disease, presented for all patients, and stratified by emergency or elective surgery. HIV excluded as <0.1% in all settings.

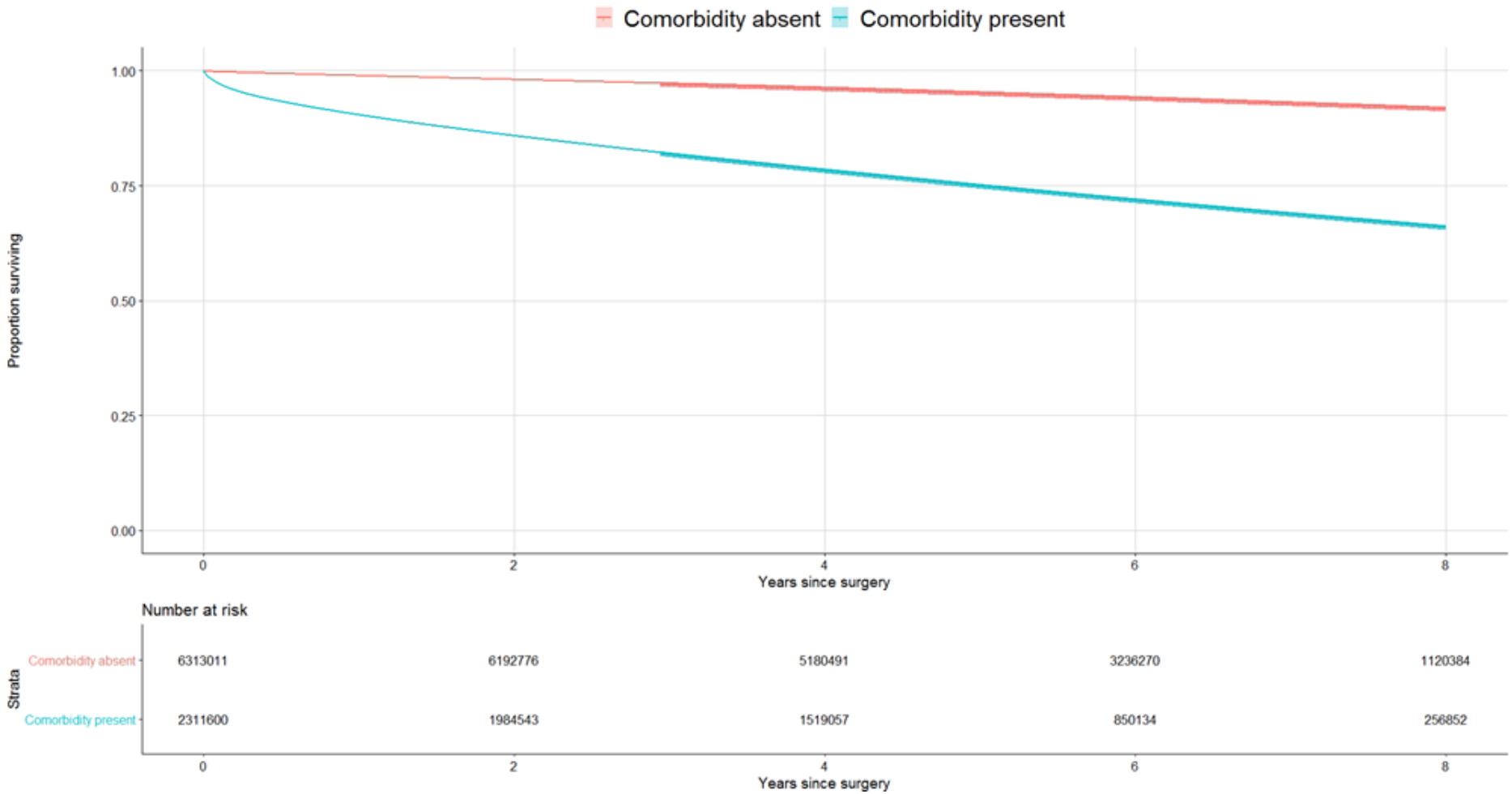

Figure 3. Proportion of patients surviving after surgery stratified by the presence or absence of long-term disease.

Supplementary content

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	All	Elective	Emergency
Bone	504357 (5.8%)	203061 (2.9%)	301296 (17.6%)
Breast	195163 (2.3%)	190007 (2.7%)	5156 (0.3%)
Cardiac	401246 (4.7%)	238770 (3.5%)	162476 (9.5%)
Cerebrovascular	11291 (0.1%)	5879 (0.1%)	5412 (0.3%)
Ear	107783 (1.2%)	99996 (1.4%)	7787 (0.5%)
Endocrine	51701 (0.6%)	49814 (0.7%)	1887 (0.1%)
Female lower genitourinary	141854 (1.6%)	127951 (1.9%)	13903 (0.8%)
Female upper genitourinary	636179 (7.4%)	543786 (7.9%)	92393 (5.4%)
Hepatopancreatobiliary	246039 (2.9%)	207414 (3%)	38625 (2.3%)
Joint	875392 (10.1%)	761495 (11%)	113897 (6.7%)
Lower gastrointestinal	955851 (11.1%)	654166 (9.5%)	301685 (17.6%)
Major Vessel	73640 (0.9%)	48859 (0.7%)	24781 (1.4%)
Male genitourinary	200281 (2.3%)	182442 (2.6%)	17839 (1%)
Muscle	234555 (2.7%)	185900 (2.7%)	48655 (2.8%)
Nasal	215734 (2.5%)	194507 (2.8%)	21227 (1.2%)
Neuro	284043 (3.3%)	248048 (3.6%)	35995 (2.1%)
Ocular	949497 (11%)	921851 (13.3%)	27646 (1.6%)
Oral	529212 (6.1%)	490803 (7.1%)	38409 (2.2%)
Orthopaedics	91842 (1.1%)	87579 (1.3%)	4263 (0.2%)
Other	71386 (0.8%)	58556 (0.8%)	12830 (0.7%)
Pharynx	90160 (1%)	87109 (1.3%)	3051 (0.2%)
Skin	753899 (8.7%)	538277 (7.8%)	215622 (12.6%)
Skull & Spine	253397 (2.9%)	210715 (3%)	42682 (2.5%)
Thoracic	121713 (1.4%)	72222 (1%)	49491 (2.9%)
Upper gastrointestinal	91285 (1.1%)	58496 (0.8%)	32789 (1.9%)
Urological	336370 (3.9%)	291089 (4.2%)	45281 (2.6%)

Vascular	200741 (2.3%)	154659 (2.2%)	46082 (2.7%)

Supplementary table 1. Frequency of procedures divided by surgical procedure grouping across different admission categories. Presented as number (% of total). ··; numbers less than 5 and therefore suppressed.

	Age 18 to 59	Age 60 to 74	Age 75 +	All
Number of patients with score				
0	4322208 (82.8%)	1332957 (63.5%)	657846 (50.3%)	6313011 (73.2%)
1	773630 (14.8%)	544578 (26%)	380607 (29.1%)	1698815 (19.7%)
2	98867 (1.9%)	158841 (7.6%)	168131 (12.9%)	425839 (4.9%)
3	18174 (0.3%)	44243 (2.1%)	66865 (5.1%)	129282 (1.5%)
4	3825 (0.1%)	13134 (0.6%)	24427 (1.9%)	41386 (0.5%)
5	913 (0%)	3610 (0.2%)	7756 (0.6%)	12279 (0.1%)
≥6	220 (0%)	1166 (0.1%)	2613 (0.2%)	3999 (0%)
Number of deaths within 90 days				
0	5483 (0.1%)	6815 (0.5%)	11838 (1.8%)	24136 (0.4%)
1	8343 (1.1%)	14974 (2.7%)	23709 (6.2%)	47026 (2.8%)
2	4299 (4.3%)	10168 (6.4%)	19755 (11.7%)	34222 (8%)
3	1473 (8.1%)	4596 (10.4%)	11444 (17.1%)	17513 (13.5%)
4	401 (10.5%)	1755 (13.4%)	5176 (21.2%)	7332 (17.7%)
5	123 (13.5%)	608 (16.8%)	1877 (24.2%)	2608 (21.2%)
≥6	31 (14.1%)	212 (18.2%)	742 (28.4%)	985 (24.6%)

Supplementary table S2. Prevalence and risk of death at 90 days after surgery at differing RCS scores across age amongst patients undergoing surgery.

Data are presented as number with percentage of patients in that age categorisation for the top panel, and percentage of patients with that count in the bottom panel. Values of 6 or greater combined together.

	2010	2011	2012	2013	2014	2015
	Proportion of all records					
Elective	1371315 (80.4%)	1247170 (80%)	1165323 (80%)	1090250 (79.9%)	1047602 (80.4%)	991791 (80.2%)
Emergency	334106 (19.6%)	310848 (20%)	291896 (20%)	274080 (20.1%)	256063 (19.6%)	244167 (19.8%)
	Number of deaths within 90 days					
All	28629 (1.7%)	25237 (1.6%)	23512 (1.6%)	21122 (1.5%)	18410 (1.4%)	16912 (1.4%)
Number of patients with > 0 diseases						
All	422143 (24.8%)	408078 (26.2%)	390623 (26.8%)	375116 (27.5%)	365833 (28.1%)	349807 (28.3%)

Supplementary table S3. Temporal accumulation of cases (top panel) and number of deaths within 90 days (bottom panel) across the study period.

RCS-Condition	Five commonest procedures				
Cardiac failure	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery	Prosthesis of lens	Cardiac pacemaker system introduced through vein	Connection of thoracic artery to coronary artery	Cardioverter defibrillator introduced through the vein
Myocardial infarction	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery	Prosthesis of lens	Connection of thoracic artery to coronary artery	Cardiac pacemaker system introduced through vein	Other excision of lesion of skin
Peripheral vascular disease	Transluminal operations on femoral artery	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery	Prosthesis of lens	Connection of thoracic artery to coronary artery	Exploration of other skin of other site
Stroke	Prosthesis of lens	Reconstruction of carotid artery	Closed reduction of fracture of bone and internal fixation	Cardiac pacemaker system introduced through vein	Prosthetic replacement of head of femur using cement
Dementia	Closed reduction of fracture of bone and internal fixation	Prosthetic replacement of head of femur using cement	Prosthesis of lens	Primary open reduction of fracture of bone and intramedullary fixation	Prosthetic replacement of head of femur not using cement
Respiratory disease	Prosthesis of lens	Surgical removal of tooth	Other excision of lesion of skin	Excision of gall bladder	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery
Rheumatological disorders	Prosthesis of lens	Total prosthetic replacement of knee joint using cement	Other excision of lesion of skin	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery	Excision of gall bladder

Liver disease	Excision of gall bladder	Prosthesis of lens	Diagnostic percutaneous operations on liver	Exteriorisation of trachea	Puncture of pleura
Diabetes mellitus	Prosthesis of lens	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery	Other excision of lesion of skin	Total prosthetic replacement of knee joint using cement	Cardiac pacemaker system introduced through vein
Hemiplegia or paraplegia	Prosthesis of lens	Closed reduction of fracture of bone and internal fixation	Primary decompression operations on lumbar spine	Prosthetic replacement of head of femur using cement	Cardiac pacemaker system introduced through vein
Chronic kidney disease	Prosthesis of lens	Cardiac pacemaker system introduced through vein	Other excision of lesion of skin	Percutaneous transluminal balloon angioplasty and insertion of stent into coronary artery	Arteriovenous shunt
Cancer	Excision of rectum	Total excision of breast	Other excision of breast	Other excision of right hemicolon	Endoscopic extirpation of lesion of bladder
Human immunodeficiency virus	Prosthesis of lens	Surgical removal of tooth	Other excision of lesion of skin	Division of bone of foot	Operations on vitreous body

Supplementary table S4. Five commonest procedures performed amongst patients with different comorbid disease conditions.

Condition	All	Elective – Day-case	Elective – Inpatient	Emergency
All patients	7.5% (653,305 of 8,624,611)	5.5% (248,375 of 4,548,806)	8.3% (197,760 of 2,364,645)	12.1% (207,170 of 1,711,160)
Congestive cardiac failure	21.2% (44,631 of 210,418)	23.5% (10,849 of 46,221)	18.4% (13,425 of 72,832)	22.3% (20,357 of 91,365)
Myocardial infarction	19.6% (27,592 of 141,043)	18.6% (7,753 of 41,591)	17.2% (10,570 of 61,556)	24.5% (9,269 of 37,896)
Peripheral vascular disease	18.9% (27,555 of 146,012)	17.3% (5,428 of 31,295)	17% (9,794 of 57,601)	21.6% (12,333 of 57,116)
Stroke	21.6% (33,323 of 154,363)	21% (8,663 of 41,187)	19.2% (8,826 of 46,022)	23.6% (15,834 of 67,154)
Dementia	23.3% (25,942 of 111,495)	24.7% (5,416 of 21,937)	25.1% (3,667 of 14,622)	22.5% (16,859 of 74,936)
Respiratory disease	12.6% (126,761 of 1,002,281)	10% (46,304 of 465,316)	12.5% (39,256 of 315,078)	18.6% (41,201 of 221,887)
Rheumatological conditions	14.9% (18,106 of 121,590)	12.8% (6,548 of 51,344)	13.3% (5,636 of 42,221)	21.1% (5,922 of 28,025)
Liver disease	21.4% (17,917 of 83,740)	18.2% (3,961 of 21,767)	19.1% (5,507 of 28,838)	25.5% (8,449 of 33,135)
Diabetes mellitus	14% (92,959 of 662,706)	11.2% (33,075 of 296,058)	13.6% (29,588 of 217,100)	20.3% (30,296 of 14,9548)
Hemiplegia or paraplegia	23.2% (8,707 of 37,518)	23.2% (2,018 of 8,712)	20.2% (2,489 of 12,293)	25.4% (4,200 of 16,513)
Chronic kidney disease	21.2% (44,325 of 208,735)	19.7% (13,984 of 71,047)	18.8% (13,149 of 69,882)	25.4% (17,192 of 67,806)
Cancer	21% (65,265 of 310,363)	22.6% (14,540 of 64,344)	19.2% (33,684 of 175,253)	24.1% (17,041 of 70,766)

Supplementary table S5. Emergency hospital readmission within one year of index surgical procedure.

Condition	All	Elective – Day-case	Elective – inpatient	Emergency
All patients	0 (0:2)	0 (0:0)	1 (1:4)	2 (1:7)
Congestive cardiac failure	3 (IQR: 0:10)	0 (IQR: 0:0)	3 (IQR: 1:8)	8 (IQR: 2:19)
Myocardial infarction	1 (IQR: 0:5)	0 (IQR: 0:0)	2 (IQR: 1:6)	5 (IQR: 1:13)
Peripheral vascular disease	3 (IQR: 0:9)	0 (IQR: 0:0)	3 (IQR: 1:7)	8 (IQR: 3:20)
Stroke	2 (IQR: 0:12)	0 (IQR: 0:0)	3 (IQR: 1:7)	11 (IQR: 3:23)
Dementia	6 (IQR: 1:18)	0 (IQR: 0:0)	2 (IQR: 1:6)	12 (IQR: 5:24)
Respiratory disease	0 (IQR: 0:2)	0 (IQR: 0:0)	1 (IQR: 1:4)	3 (IQR: 1:11)
Rheumatological conditions	1 (IQR: 0:4)	0 (IQR: 0:0)	2 (IQR: 1:5)	6 (IQR: 2:15)
Liver disease	2 (IQR: 0:8)	0 (IQR: 0:0)	2 (IQR: 1:6)	7 (IQR: 2:17)
Diabetes mellitus	0 (IQR: 0:3)	0 (IQR: 0:0)	2 (IQR: 1:5)	5 (IQR: 1:13)
Hemiplegia or paraplegia	3 (IQR: 0:12)	0 (IQR: 0:0)	2 (IQR: 1:8)	10 (IQR: 3:24)
Chronic kidney disease	1 (IQR: 0:8)	0 (IQR: 0:0)	3 (IQR: 1:6)	9 (IQR: 3:20)
Cancer	3 (IQR: 0:7)	0 (IQR: 0:0)	3 (IQR: 1:7)	8 (IQR: 3:17)

Supplementary table S6. Length of hospital stay reported in days. Data are presented as median (interquartile range) days.

	Odds ratio (95%CI)
Age	1.1 (1.1 to 1.1)
Sex[+] (male vs. female)	 1.2 (1.2 to 1.2)
Admission category (emergency vs. elective)	 9 (8.9 to 9.1)
Year	
2010	Reference
2011	0.9 (0.9 to 1)
2012	0.9 (0.9 to 1)
2013	0.9 (0.9 to 0.9)
2014	0.8 (0.8 to 0.8)
2015	0.8 (0.8 to 0.8)
RCS-Score diseases	
Cardiac failure	2.4 (2.4 to 2.5)
Myocardial infarction	1 (1 to 1.1)
Peripheral vascular disease	1.9 (1.9 to 2)
Stroke	1.6 (1.6 to 1.6)
Dementia	2 (1.9 to 2)
Respiratory disease	1.6 (1.6 to 1.7)
Rheumatological diseases	1.1 (1.1 to 1.1)
Liver disease	4.5 (4.4 to 4.6)
Diabetes mellitus	1.1 (1.1 to 1.1)
Hemiplegia or paraplegia	1.2 (1.1 to 1.2)
Chronic kidney disease	1.5 (1.4 to 1.5)
Cancer	8.3 (8.2 to 8.5)
Human immunodeficiency virus	0 (0 to >20)

Supplementary table S7. Summary of multivariable model demonstrating the odds ratio for death at 90 days after surgical procedures. Multivariable model included age as a continuous variable and all others as factors. SE; Standard Error. [+]Unspecified sex was omitted from modelling. *; p value < 0.001. Mc-Faddens pseudo-R^2 = 0.356, C statistic = 0.928, n = 8620363, events = 133818.

	Coronary artery bypass graft	Total hip replacement	Colorectal resection	Cataract
Number	43063	158546	100667	585470
Age				
Mean (SD)	66.2 (9.8)	67.1 (11.3)	58.7 (16.9)	73.7 (11.1)
Median (IQR)	67 (60 to 74)	68 (61 to 75)	62 (47 to 71)	75 (67 to 82)
Sex*				
Male	35603 (82.7 %)	65332 (41.2 %)	50686 (50.4 %)	237947 (40.6 %)
Female	7459 (17.3 %)	92936 (58.6 %)	49961 (49.6 %)	346283 (59.1 %)
Year				
2010	9222 (21.4 %)	30473 (19.2 %)	20412 (20.3 %)	113566 (19.4 %)
2011	8190 (19 %)	28536 (18 %)	18967 (18.8 %)	101787 (17.4 %)
2012	7379 (17.1 %)	27174 (17.1 %)	17798 (17.7 %)	95978 (16.4 %)
2013	6792 (15.8 %)	25111 (15.8 %)	15668 (15.6 %)	92419 (15.8 %)
2014	6113 (14.2 %)	24452 (15.4 %)	14413 (14.3 %)	92678 (15.8 %)
2015	5367 (12.5 %)	22800 (14.4 %)	13409 (13.3 %)	89042 (15.2 %)
RCS-Score				

>=1	30277 (70.3%)	44927 (28.3%)	54904 (54.5%)	226567 (38.7%)

Supplementary table S8. Characteristics of patients undergoing four pre-specified procedures. SD, standard deviation; IQR, interquartile range. Numbers less than 5 are suppressed and are expressed as number (%) unless otherwise stated. Admission category based on admission method and patient class. * 1539 records with unspecified sex omitted.

	Coronary artery bypass graft	Total hip replacement	Colorectal resection	Cataract
Number	43063	158546	100667	585470
Congestive cardiac failure	9913 (23 %)	2486 (1.6 %)	1898 (1.9 %)	17591 (3 %)
Myocardial infarction	12347 (28.7 %)	2249 (1.4 %)	1404 (1.4 %)	16590 (2.8 %)
Peripheral vascular disease	4836 (11.2 %)	1579 (1 %)	1791 (1.8 %)	7472 (1.3 %)
Stroke	2818 (6.5 %)	1920 (1.2 %)	1410 (1.4 %)	15415 (2.6 %)
Dementia	142 (0.3 %)	939 (0.6 %)	622 (0.6 %)	9850 (1.7 %)
Respiratory disease	6975 (16.2 %)	19469 (12.3 %)	13199 (13.1 %)	88313 (15.1 %)
Rheumatological conditions	1006 (2.3 %)	4921 (3.1 %)	1578 (1.6 %)	14229 (2.4 %)
Liver disease	457 (1.1 %)	779 (0.5 %)	1769 (1.8 %)	3479 (0.6 %)
Diabetes mellitus	11708 (27.2 %)	13546 (8.5 %)	9558 (9.5 %)	106108 (18.1 %)
Hemiplegia or paraplegia	284 (0.7 %)	329 (0.2 %)	381 (0.4 %)	2528 (0.4 %)
Chronic kidney disease	2874 (6.7 %)	6394 (4 %)	2882 (2.9 %)	28663 (4.9 %)
Cancer	893 (2.1 %)	1867 (1.2 %)	41623 (41.3 %)	8267 (1.4 %)

Supplementary table S9. Prevalence of RCS score conditions amongst patients undergoing four pre-specified procedures. Data are presented as number (%) unless otherwise stated. Human immunodeficiency virus omitted as very low numbers required suppression for all procedures.

	Coronary artery bypass graft	Total hip replacement	Colorectal resection	Cataract
Number	43063	158546	100667	585470
90-day death	914 (2.1 %)	552 (0.3 %)	1655 (1.6 %)	2853 (0.5 %)
Hospital readmission	4837 (11.2 %)	9262 (5.8 %)	12251 (12.2 %)	54930 (9.4 %)
Length of hospital stay (days; median [IQR])	6 (5 to 9)	4 (3 to 5)	5 (0 to 8)	0 (0 to 0)

Supplementary table S10. Outcomes after elective surgery for four specified procedures. Data are presented as n (%) or median (IQR). Death data from linkage to Office for National Statistics civil registration data. Readmission within one year determined from hospital episode statistics admitted patient care and includes any emergency admission within 365 days of index surgical procedure.

	Coronary artery bypass graft	Total hip replacement	Colorectal resection	Cataract
Overall	914 (2.1%)	552 (0.3%)	1655 (1.6%)	2853 (0.5%)
RCS-Score conditions				
Congestive cardiac failure	515 (5.2 %)	80 (3.2 %)	239 (12.6 %)	461 (2.6 %)
Myocardial infarction	321 (2.6 %)	29 (1.3 %)	67 (4.8 %)	223 (1.3 %)
Peripheral vascular disease	207 (4.3 %)	28 (1.8 %)	150 (8.4 %)	158 (2.1 %)
Stroke	168 (6 %)	49 (2.6 %)	112 (7.9 %)	228 (1.5 %)
Dementia	14 (9.9 %)	45 (4.8 %)	62 (10 %)	212 (2.2 %)
Respiratory disease	277 (4 %)	131 (0.7 %)	355 (2.7 %)	899 (1 %)
Rheumatological conditions	45 (4.5 %)	21 (0.4 %)	43 (2.7 %)	112 (0.8 %)
Liver disease	67 (14.7 %)	13 (1.7 %)	111 (6.3 %)	74 (2.1 %)
Diabetes mellitus	320 (2.7 %)	97 (0.7 %)	307 (3.2 %)	704 (0.7 %)
Hemiplegia or paraplegia	13 (4.6 %)	·· (<5%)	19 (5 %)	34 (1.3 %)
Chronic kidney disease	211 (7.3 %)	103 (1.6 %)	174 (6 %)	449 (1.6 %)
Cancer	46 (5.2 %)	65 (3.5 %)	1182 (2.8 %)	309 (3.7 %)

Supplementary table S11. Number of deaths within 90 days of surgery amongst individuals with different RCS score conditions. Data presented as n (%). ·· numbers < 5 and so suppressed.

Variable	Coronary artery bypass graft	Total hip replacement	Colorectal resection	Cataract
Age	2.5 (2.3 to 2.9)	3.3 (2.9 to 3.9)	4.6 (4.1 to 5.2)	3 (2.8 to 3.3)
Sex (Male vs Female)	1.3 (1.1 to 1.5)	1.4 (1.1 to 1.6)	0.7 (0.6 to 0.8)	1.5 (1.4 to 1.6)
Year				
2011 vs. 2010	0.8 (0.7 to 1)	0.7 (0.6 to 1)	0.7 (0.6 to 0.9)	1 (0.9 to 1.1)
2012 vs. 2010	0.8 (0.6 to 1)	0.8 (0.6 to 1.1)	0.8 (0.7 to 0.9)	1 (0.9 to 1.1)
2013 vs. 2010	0.8 (0.6 to 1)	0.6 (0.5 to 0.9)	0.7 (0.6 to 0.8)	0.9 (0.8 to 1)
2014 vs. 2010	0.7 (0.6 to 0.9)	0.6 (0.5 to 0.9)	0.5 (0.4 to 0.6)	1 (0.9 to 1.1)
2015 vs. 2010	0.6 (0.5 to 0.8)	0.5 (0.4 to 0.7)	0.5 (0.4 to 0.6)	0.8 (0.7 to 1)
RCS-score conditions*				
Congestive cardiac failure	3 (2.6 to 3.4)	3.6 (2.8 to 4.7)	3.7 (3.1 to 4.3)	2.5 (2.2 to 2.8)
Myocardial infarction	1.1 (0.9 to 1.3)	1.7 (1.1 to 2.6)	1.1 (0.8 to 1.4)	1.2 (1.1 to 1.4)
Peripheral vascular disease	1.5 (1.3 to 1.8)	2 (1.3 to 3.1)	2.6 (2.1 to 3.1)	1.9 (1.6 to 2.3)
Stroke	2.1 (1.7 to 2.5)	2.4 (1.7 to 3.5)	2 (1.6 to 2.5)	1.3 (1.1 to 1.5)
Dementia	2.2 (1.2 to 4)	4.7 (3.3 to 6.8)	2.3 (1.7 to 3)	2.2 (1.9 to 2.6)
Respiratory disease	1.7 (1.4 to 1.9)	1.8 (1.5 to 2.2)	1.4 (1.2 to 1.5)	2.1 (1.9 to 2.2)
Rheumatological conditions	1.4 (1 to 2)	0.9 (0.6 to 1.5)	1 (0.7 to 1.4)	1.1 (0.9 to 1.4)
Liver disease	7.5 (5.6 to 10.1)	4.4 (2.4 to 8.1)	3 (2.4 to 3.7)	3.4 (2.6 to 4.3)

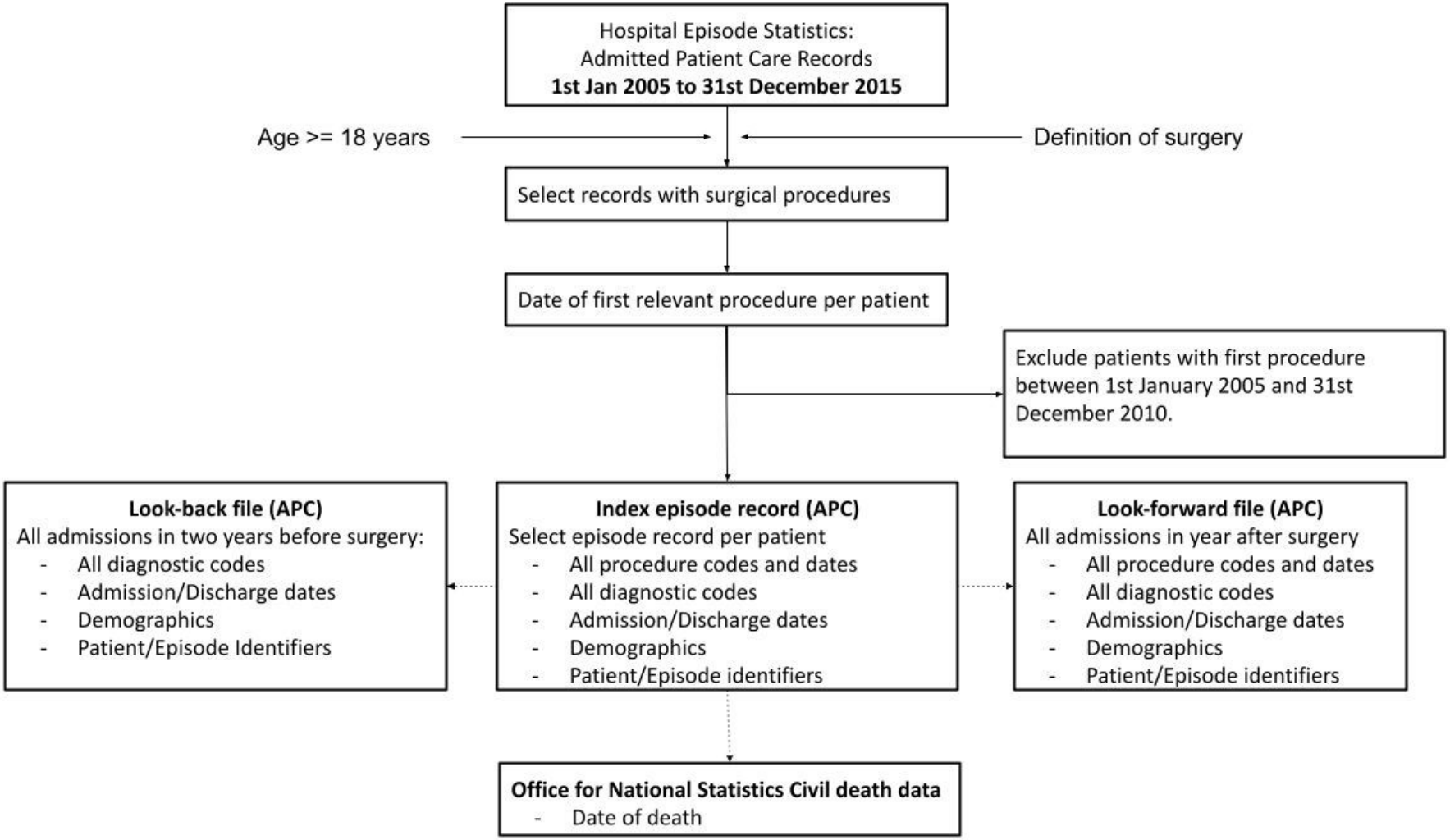
Diabetes mellitus	1.2 (1.1 to 1.4)	1.5 (1.2 to 1.9)	1.2 (1 to 1.3)	1.3 (1.2 to 1.4)
Hemiplegia or paraplegia	0.8 (0.5 to 1.5)	1.1 (0.4 to 2.8)	0.9 (0.6 to 1.6)	1.1 (0.8 to 1.6)
Chronic kidney disease	2.1 (1.8 to 2.5)	1.9 (1.5 to 2.4)	1.3 (1.1 to 1.5)	1.4 (1.3 to 1.6)
Cancer	1.6 (1.2 to 2.3)	6.2 (4.7 to 8.2)	1.7 (1.5 to 1.9)	4.7 (4.1 to 5.3)

Supplementary table 12. Summary outputs of multivariable logistic regression models across four sensitivity procedure groupings. Presented as odds ratio with 95% confidence interval. Age is presented comparing quartile 1 to quartile 3. *HIV removed as the disease prevalence was very low in all subgroups.

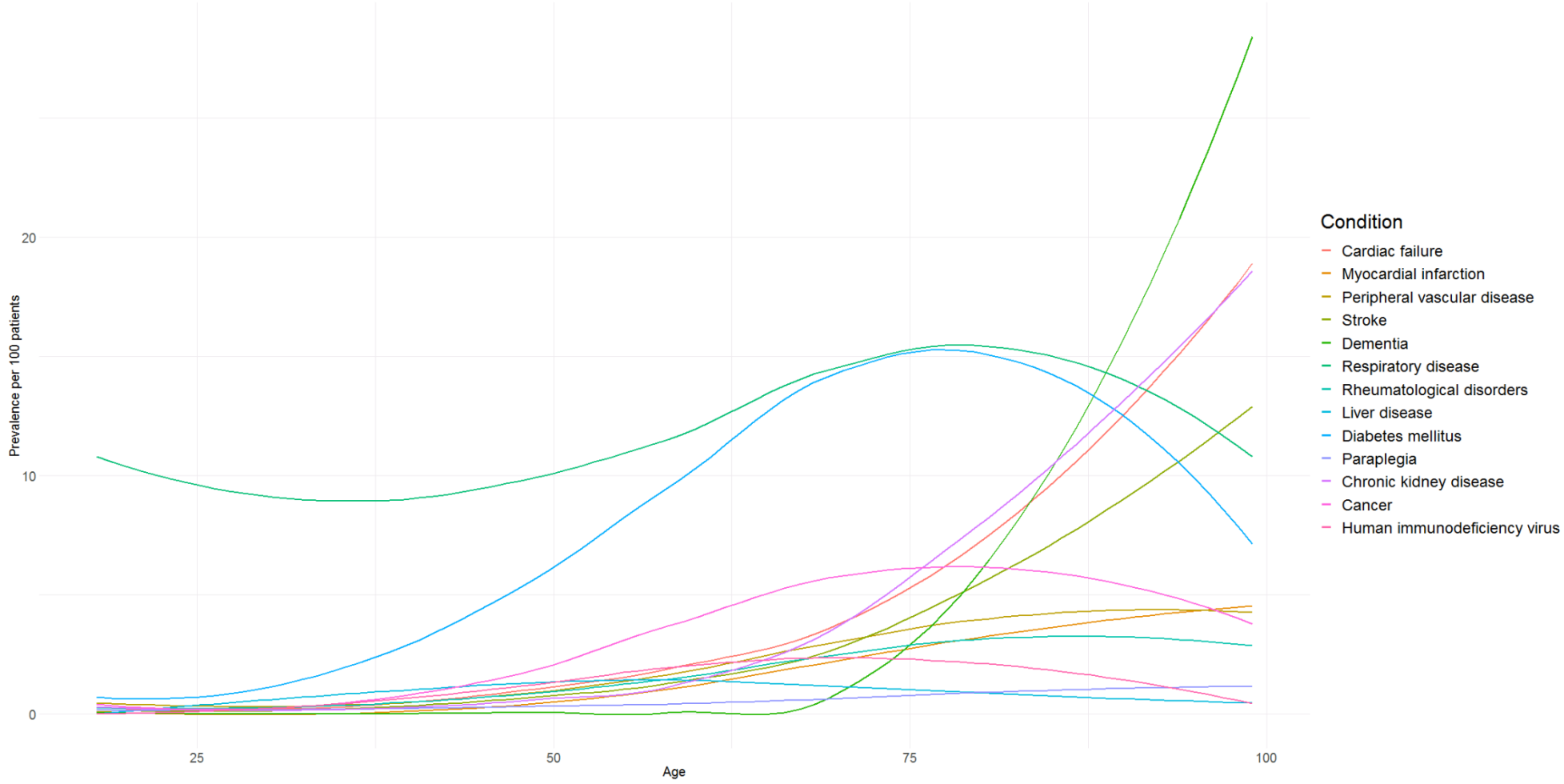
	Coefficient (SE)	OR (95%CI)
Intercept	-8.7216 (0.016)	NA
Age	0.0556 (0.0002)*	5.9 (5.8 to 6)
Male: Female	-0.2838 (0.0061)*	1.3 (1.3 to 1.3)
Emergency: Elective	2.166 (0.0066)*	8.7 (8.6 to 8.8)
2011: 2010	-0.0485 (0.0094)*	1 (0.9 to 1)
2012: 2010	-0.0471 (0.0096)*	1 (0.9 to 1)
2013: 2010	-0.0983 (0.0099)*	0.9 (0.9 to 0.9)
2014: 2010	-0.1537 (0.0103)*	0.9 (0.8 to 0.9)
2015: 2010	-0.1811 (0.0106)*	0.8 (0.8 to 0.9)
Congestive cardiac failure	0.951 (0.0098)*	2.6 (2.5 to 2.6)
Myocardial infarction	0.1367 (0.0167)*	1.1 (1.1 to 1.2)
Peripheral vascular disease	0.5954 (0.0133)*	1.8 (1.8 to 1.9)
Stroke	0.3288 (0.0115)*	1.4 (1.4 to 1.4)
Dementia	0.5198 (0.0098)*	1.7 (1.6 to 1.7)
Respiratory disease	0.2801 (0.0077)*	1.3 (1.3 to 1.3)
Rheumatological conditions	0.2182 (0.018)*	1.2 (1.2 to 1.3)
Liver disease	1.6716 (0.0144)*	5.3 (5.2 to 5.5)
Diabetes mellitus	0.1719 (0.0081)*	1.2 (1.2 to 1.2)
Hemiplegia or paraplegia	0.1441 (0.0242)*	1.2 (1.1 to 1.2)
Chronic kidney disease	0.4059 (0.01)*	1.5 (1.5 to 1.5)
Cancer	1.7719 (0.0131)*	5.9 (5.7 to 6)
HIV	-5.5411 (20.4244)	0 (0.0 to >20)

Supplementary table 13. Summary of multivariable model demonstrating the odds ratio for death at 90 days after surgical procedures associated with different disease conditions after removing conditions possibly associated with the index procedure. For example for congestive cardiac failure, patients undergoing cardiac surgical procedures are excluded. Multivariable model included age as a continuous

variable and all others as factors. [+]Unspecified sex was omitted from modelling. *; p value < 0.001. Mc-Faddens pseudo-R^2 = 0.311, C statistic = 0.907, n = 8637275, events = 133837.

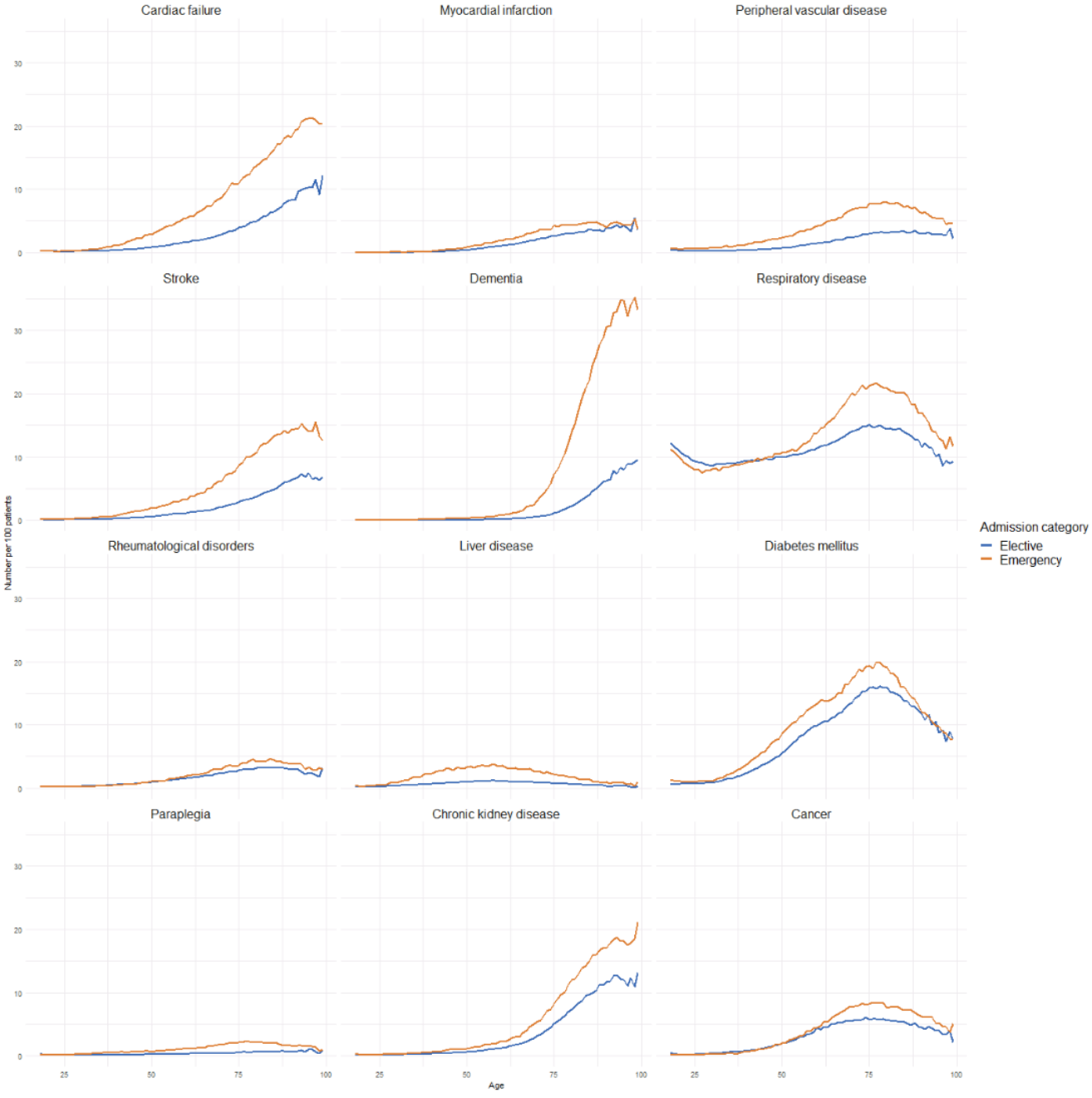

Hospital Episode Statistics:
Admitted Patient Care Records
1st Jan 2005 to 31st December 2015
Age >= 18 years
Definition of surgery
Select records with surgical procedures
Date of first relevant procedure per patient
Exclude patients with first procedure between 1st January 2005 and 31st December 2010.
Look-back file (APC)
All admissions in two years before surgery:
- All diagnostic codes
- Admission/Discharge dates
- Demographics
- Patient/Episode Identifiers
Index episode record (APC)
Select episode record per patient
- All procedure codes and dates
- All diagnostic codes
- Admission/Discharge dates
- Demographics
- Patient/Episode identifiers
Look-forward file (APC)
All admissions in year after surgery
- All procedure codes and dates
- All diagnostic codes
- Admission/Discharge dates
- Demographics
- Patient/Episode identifiers
Office for National Statistics Civil death data
- Date of death

Supplementary figure 1. **Flow of record selection and derivation of index record, look-back and look-forward files.** APC; Admitted Patient Care dataset.

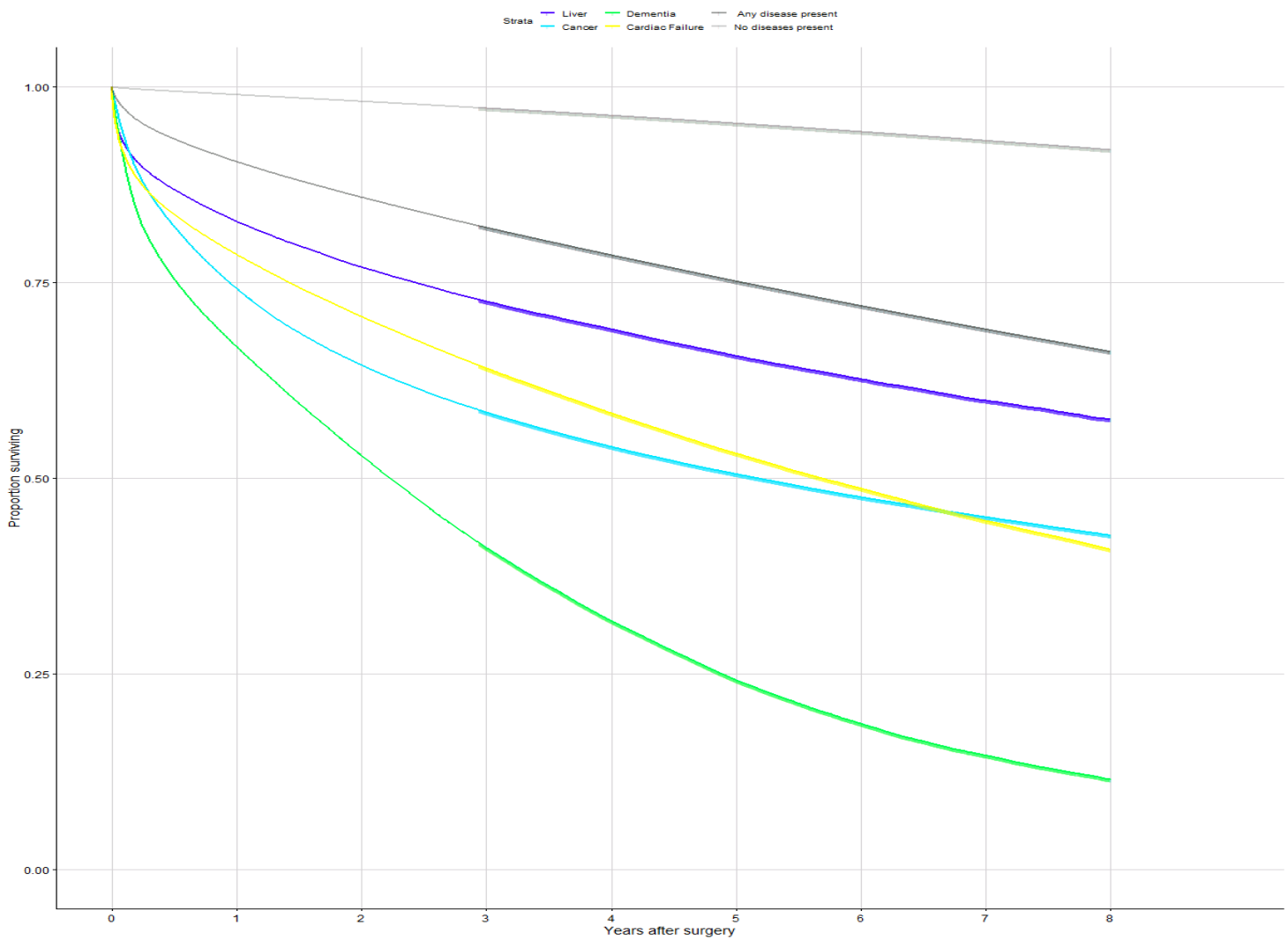


Supplementary figure S2. Percentage of patients undergoing surgery with different long-term diseases presented between the ages of 18 and 100.

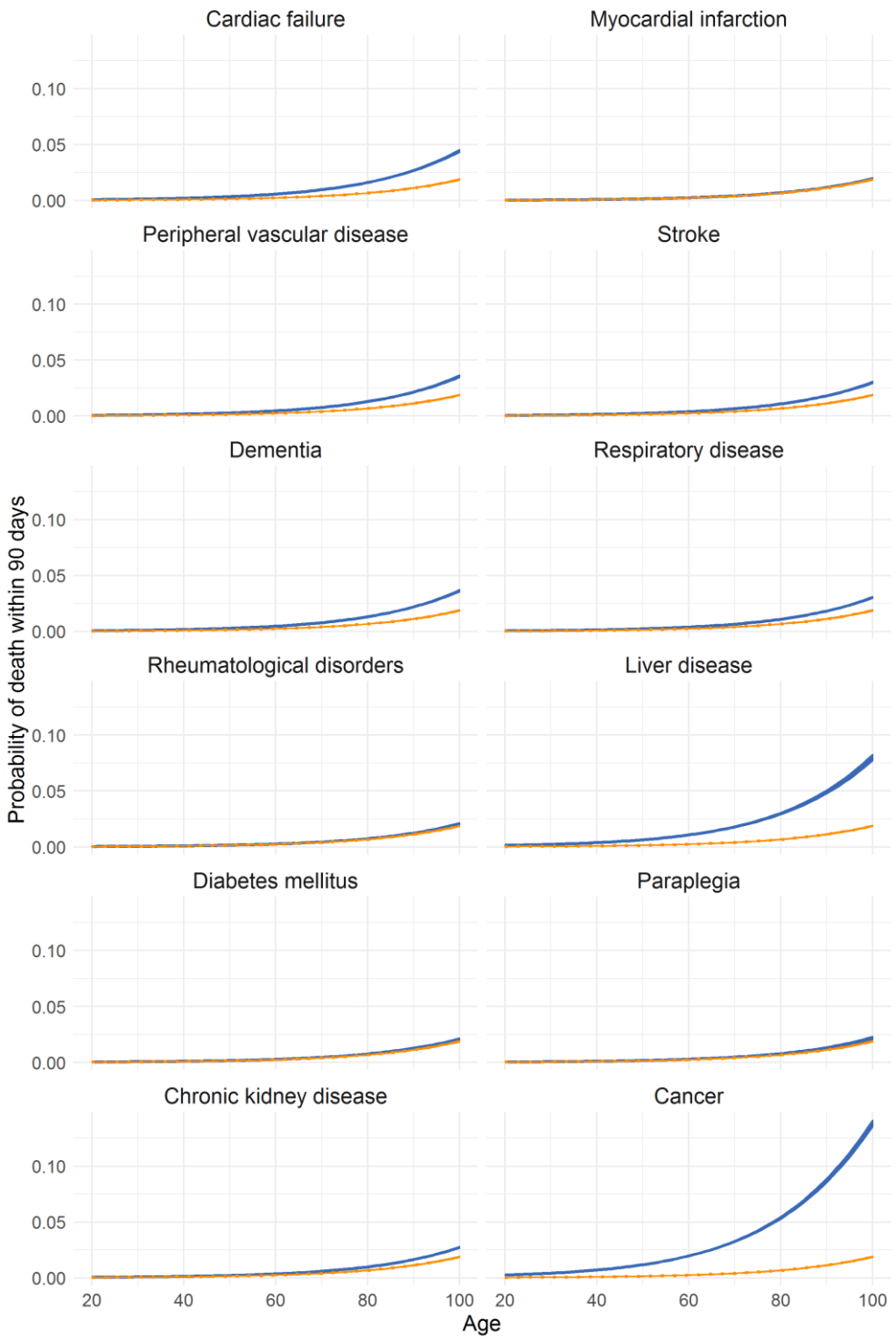
Proportion is the number suffering that disease divided by the total number of persons undergoing surgery with that disease.



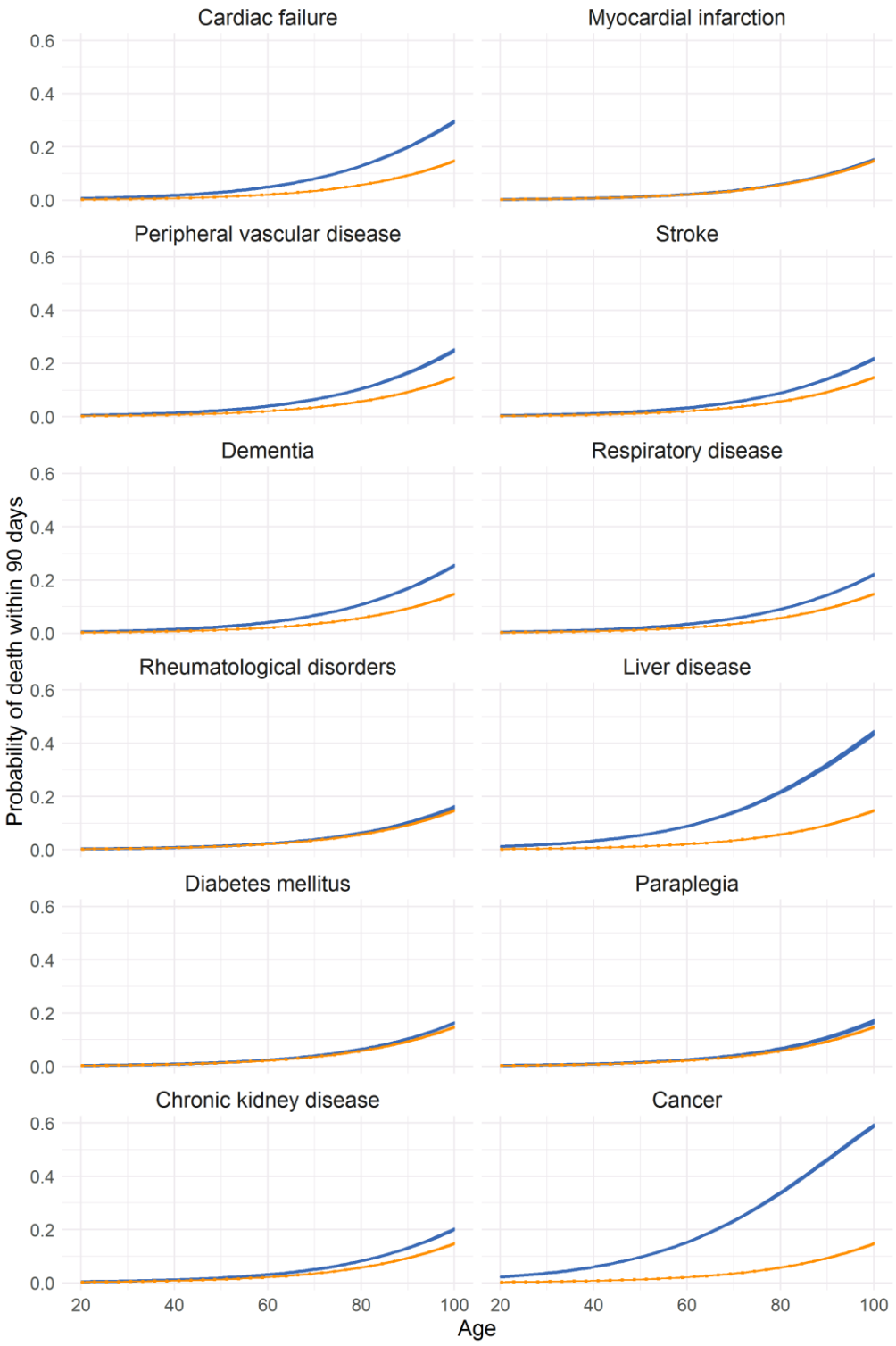
Supplementary Figure S3. Percentage of patients undergoing surgery with different chronic diseases, divided to elective or emergency procedures and presented between the ages of 18 and 100. Proportion is the number suffering that disease divided by the total number of persons undergoing surgery with that disease. Human immunodeficiency virus omitted as <0.1% of patients had the disease at any time.


Strata
Liver
Cancer
Dementia
Cardiac Failure
Any disease present
No diseases present
1.00
0.75
0.50
0.25
0.00
Proportion surviving
0
1
2
3
4
5
6
7
8
Years after surgery

Supplementary Figure S4. Kaplan-Meier survival curves among patients following surgery. Four conditions identified as high risk were identified with an adjusted odds ratio >2.0 (dementia, liver disease, cardiac failure, cancer). Additional lines indicate the survival of those with any disease, and patients with no diseases.



Supplementary Figure S5. Adjusted probability of death within 90 days of elective surgery associated with each RCS-score disease between the ages of 18 and 100 years. Probability of death within 90 days derived from a multivariable model adjusting for age, presence of all diseases, sex, and year. In the graphs above, the predictions are made for women having a procedure in 2013, with only the specified disease. The orange line is the base model for risk among patients who do not have any RCS Charlson diseases.



Supplementary Figure S6. Adjusted probability of death within 90 days of emergency surgery associated with each RCS-score disease between the ages of 18 and 100 years. Probability of death within 90 days derived from a multivariable model adjusting for age, presence of all diseases, sex, and year. In the graphs above, the predictions are made for women having a procedure in 2013, with only the specified disease. The orange line is the base model for risk among patients who do not have any RCS Charlson diseases.

SUPPLEMENTARY METHODS

Differences from protocol:

A prospectively developed protocol was developed prior to starting analysis. Several changes were made in the conduct of the study. Certain outcomes not reported in this analysis will be address in forthcoming manuscripts:

1. IMD data was not available before 2011 as this was only a table one variable, decided to drop it rather than estimating IMD for all records <2011.
2. Bed days per year was an overly complex outcome measure and plan to explore in a methodological paper.

Refinement of surgical definition

After applying the intermediate definition of surgery, which was based on three-character codes, the top 200 commonest four-character OPCS codes were reviewed. Two authors (AF, TA) independently reviewed these and any minimally invasive non-surgical procedures, for example L71.4 which is commonly used for bedside arterial line insertion but does not reflect a surgical procedure. The list of four-character procedures that were removed are outlined in appendix A.

SUPPLEMENTARY RESULTS

Sensitivity analyses

We selected four elective surgical settings to explore variation in the prevalence of conditions, and if there was a different relationship between conditions and outcomes. The characteristics of patients undergoing these four procedures is summarised in supplementary table S7 and the prevalence of conditions in supplementary table S8. We excluded human immune-deficiency virus from all tables because it was very infrequently reported (<0.01% in all procedure groups).

Coronary artery bypass grafting (CABG) was selected as it is a procedure that provides population level, prognostic benefit. Some 43,063 patients undergoing coronary artery bypass grafting as their first procedure were identified. Patients undergoing CABG were older than the wider surgical population (median age 51 years; IQR 34 to 67), they had a median age of 67 years (IQR: 60 to 74) and 82.7% were male (35,603). 70.3% of patients had one or more condition captured using the RCS-score, of which myocardial infarction was the most frequent (28.7%; 12,347).

Colorectal resection was selected as it is a procedure that provides individual, patient level prognostic benefit. 100,667 patients undergoing colorectal resection as their first procedure were identified, they had a median age of 62 years (IQR: 47 to 71), and 50,686 (50.4%) were male. Just over half of these patients had a chronic condition (54.5%), the most frequent was cancer (41.3%; 41,623).

Total hip replacement (THR) was selected because it is a procedure providing symptomatic relief, with the aim to improve quality of life. 158,546 patients with a median age of 68 years (IQR: 61 to 75) underwent THR as their first procedure, of whom 41.2% were male. 28.3% of patients undergoing THR had at least one condition and respiratory disease was the commonest (12.3%; 19,469).

Cataract replacement was selected because it is a low-risk procedure performed in very high volumes. 585,470 patients undergoing this procedure with a median age of 75 years (IQR: 67 to 82) were identified, 40.6% were male. 38.7% of these patients had at least one condition, and diabetes mellitus was the commonest (18.1%; 106,108).

The proportion of deaths within 90 days of surgery was highest amongst patients undergoing CABG (2.1%; 914). The risk of death within 90 days after total hip replacement (0.3%; 552) and cataract (0.5%; 2853) was very low. The crude rate of death associated with different conditions varied greatly

depending on the procedure (supplementary tables S9 & S10). For example, the risk of death amongst patients with congestive cardiac failure ranged from 2.6% undergoing cataract procedure to 12.6% undergoing colorectal cancer resection.

After adjustment for age, sex, year of procedure and all other conditions, three were consistently associated with double the odds of death within 90 days after surgery amongst those in any of the four groups: congestive cardiac failure, dementia, and liver disease (supplementary table S11). Some conditions had a consistent association with outcome across procedure groups (e.g. Diabetes mellitus), while others were much more variable (e.g. Chronic kidney disease). We observed some seemingly paradoxical relationships, for example, cancer was associated with a greater adjusted odd of death amongst patients undergoing cataract resection (OR 4.7 [4.1 to 5.3]) and total hip replacement (OR 6.2 [4.7 to 8.2]) than colorectal resection (OR 1.7 [1.5 to 1.9]).

APPENDIX A: FOUR CHARACTER OPCS 4.7 CODES REMOVED

Code	Description
A84.*	Neurophysiological interventions
J13.2	Percutaneous biopsy of lesion of liver NEC
L71.4	Percutaneous transluminal cannulation of artery
L91.1	Open insertion of central venous catheter
L91.2	Insertion of central venous catheter NEC
L91.3	Attention to central venous catheter NEC
L91.4	Removal of central venous catheter
L91.6	Cannulation of vein NEC
L99.7	Percutaneous transluminal peripheral insertion of central catheter
M13.1	Percutaneous needle biopsy of lesion of kidney
M70.2	Perineal needle biopsy of prostate
M70.3	Rectal needle biopsy of prostate
T12.3	Aspiration of pleural cavity
T12.4	Insertion of tube drain into pleural cavity

APPENDIX B: CODES DEFINING PROTOTYPICAL PROCEDURES

Coronary artery bypass grafting procedure	Code
Saphenous vein graft replacement of coronary artery	K40
Allograft replacement of coronary artery	K42
Prosthetic replacement of coronary artery	K43
Other replacement of coronary artery	K44
Connection of thoracic artery to coronary artery	K45
Other bypass of coronary artery	K46
Repair of coronary artery	K47
Other open operations on coronary artery	K48

Colorectal resection	Code
Total excision of colon and rectum	H04
Total excision of colon	H05
Extended excision of right hemicolon	H06
Other excision of right hemicolon	H07
Excision of transverse colon	H08
Excision of left hemicolon	H09
Excision of sigmoid colon	H10
Other excision of colon	H11
Extirpation of lesion of colon	H12
Bypass of colon	H13
Exteriorisation of caecum	H14
Other exteriorisation of colon	H15
Incision of colon	H16
Intra-abdominal manipulation of colon	H17
Open endoscopic operations on colon	H18

Other open operations on colon	H19
Subtotal excision of colon	H29
Other operations on colon	H30
Excision of rectum	H33
Open extirpation of lesion of rectum	H34
Other operations on rectum	H46
Excision of anus	H47
Excision of lesion of anus	H48
Other operations on bowel	H62
Major joint replacement procedure	**Code**
Total prosthetic replacement of hip joint using cement	W37
Total prosthetic replacement of hip joint not using cement	W38
Other total prosthetic replacement of hip joint	W39
Prosthetic replacement of head of femur using cement	W46
Prosthetic replacement of head of femur not using cement	W47
Other prosthetic replacement of head of femur	W48
Hybrid prosthetic replacement of hip joint using cemented acetabular component	W93
Hybrid prosthetic replacement of hip joint using cemented femoral component	W94
Hybrid prosthetic replacement of hip joint using cement	W95
Cataract procedures	
Prosthesis of lens	C75