




# BMJ Open Postoperative mortality in New Zealand following general anaesthetic: demographic patterns and temporal trends

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## ABSTRACT

**Objectives** In this manuscript, we describe broad trends in postoperative mortality in New Zealand (a country with universal healthcare) for acute and elective/waiting list procedures conducted between 2005 and 2017.

**Design, participants and setting** We use high-quality national-level hospitalisation data to compare the risk of postoperative mortality between demographic subgroups after adjusting for key patient-level confounders and mediators. We also present temporal trends and consider how rates in postoperative death following acute and elective/waiting list procedures have changed over this time period.

**Results and conclusion** A total of 1 836 683 unique patients accounted for 3 117 374 admissions in which a procedure was performed under general anaesthetic over the study period. We observed an overall 30-day mortality rate of 0.5 per 100 procedures and a 90-day mortality rate of 0.9 per 100. For acute procedures, we observed a 30-day mortality rate of 1.6 per 100, compared with 0.2 per 100 for elective/waiting list procedures. In terms of procedure specialty, respiratory and cardiovascular procedures had the highest rate of 30-day mortality (age-standardised rate, acute procedures: 3–6 per 100; elective/waiting list: 0.7–1 per 100). As in other contexts, we observed that the likelihood of postoperative death was not proportionally distributed within our population: older patients, Māori patients, those living in areas with higher deprivation and those with comorbidity were at increased risk of postoperative death, even after adjusting for all available factors that might explain differences between these groups. Increasing procedure risk (measured using the Johns Hopkins Surgical Risk Classification System) was also associated with an increased risk of postoperative death. Encouragingly, it appears that risk of postoperative mortality has declined over the past decade, possibly reflecting improvements in perioperative quality of care; however, this decline did not occur equally across procedure specialties.

## INTRODUCTION

More than four million people die within 30 days of surgery every year.<sup>1</sup> Of the 1.2 million admissions in New Zealand between 2009

## Strengths and limitations of this study

- A key strength of this study is the national and temporal coverage of the surgical cohort and outcome data.
- Another key strength is the national data linkage available in New Zealand, which enabled us to follow patients beyond their discharge from hospital in order to measure 30-day and 90-day mortality outcomes.
- We have intentionally focused exclusively on procedures performed under general anaesthesia, and therefore do not include procedures performed under neuraxial block and/or regional anaesthesia.
- Due to data availability, it was not possible in our study to adequately investigate the role of hospital volume or clustering of patients at a hospital level.

and 2013 for procedures performed under general anaesthesia, 0.6% were followed by a death within 30 days, with the majority (72%) occurring following an acute admission.<sup>2</sup>

In a clinical setting, the key means of preventing postoperative complications (and death) include: (a) patient selection, using tools such as risk calculators<sup>3</sup>, (b) optimisation of the condition of the patient (which may include ‘prehabilitation’), (c) altering operation and treatment modalities to suit the needs and condition of the patient, (d) preoperative prevention measures including adherence to robust and standardised clinical checklists and (e) good postoperative management, including management of comorbidities<sup>4</sup> and selection of the postoperative location (eg, ward, intensive care, outside hospital). Adherence to these factors will vary between clinical contexts and should change over time as new and improved standards are developed and implemented.

The risk of postoperative mortality is not proportionally shared across the population. In terms of patient-level factors, advancing age,<sup>5–7</sup> minority or indigenous ethnicity<sup>8–16</sup> and socioeconomic deprivation<sup>2 17–19</sup> are known to confer increased risk of postoperative death. Patient comorbidity is also a strong risk factor, with risk of postoperative death increasing with comorbidity severity.<sup>20–22</sup> These (and other) risk factors do not act in isolation from each other: rather, they combine with the type and complexity of the procedure being undertaken (ie, severity or risk) and the urgency of the procedure (ie, acuity) to attenuate or amplify an individual's risk of death following surgery.

In this manuscript, we describe trends in postoperative mortality in New Zealand (a country with universal healthcare) for acute and elective/waiting list procedures conducted between 2005 and 2017. We compare the risk of postoperative mortality between demographic subgroups after adjusting for key patient-level confounders and mediators. We also present temporal trends and consider how rates in postoperative death following acute and elective/waiting list procedures have changed over this time period.

## METHODS

### Participants and data sources

Our study cohort included all individuals who underwent a procedure under general anaesthesia (International Classification of Diseases [ICD-10-AM] third edition codes: 9251410–9251499) between 1 January 2005 and 31 December 2017. National-level hospitalisation data (National Minimum Dataset, NMDS<sup>23</sup> from all publicly funded procedures were included as well as privately funded procedures conducted in those private hospitals that report to the national collections. New Zealand has 84 public hospitals and 73 private hospitals,<sup>24</sup> with the completeness of reporting of privately funded procedures varying annually.<sup>25</sup> These data were used to find eligible hospital admissions over the study period that included procedures performed under general anaesthetic. To allow for patients who had more than one operation performed under general anaesthetic during their admission, admissions were further divided into the individual days that procedures were performed during the admission, and this was used as the unit of analysis for this study.

Using the residency flag on the NMDS, we restricted our analysis to New Zealand residents to ensure follow-up for postoperative death, which resulted in the exclusion of 103 617 procedures (3.1% of all procedures). We excluded patients who had an American Society of Anaesthesiologists (ASA) score of 6 (indicating that the procedure was being undertaken on patients with irreversible cessation of brain function for the purposes of organ donation) or were coded as having a removal of a donor heart or lung, which resulted in the exclusion of 250 procedures (<0.01% of all procedures).

Patient comorbidity at the start of each admission (see the Variables below) was measured using data on recorded diagnoses from public and private hospital admission records for the 5-year period prior to the admission using an encrypted patient identifier (National Health Index number, NHI). Date of death was defined using the date of death variable that appears on the NHI dataset, which is derived from the births, deaths and marriages office.<sup>26</sup>

### Variables

All variables were derived from the NMDS dataset. Procedure specialty was determined by mapping each procedure code to the Australasian College of Health Informatics procedure code 'block', which is comprised of blocks of procedures organised according to anatomical specialty.<sup>27</sup> Procedure risk was established using a modified version<sup>3</sup> of the Johns Hopkins Surgical Risk Classification System,<sup>28</sup> which classifies surgical risk into five categories according to factors such as the invasive nature of the procedure and the potential for blood loss. Procedure codes were mapped to the risk classification system as part of a previous study.<sup>3</sup>

Patient age was defined at the time of procedure (categorised as <25, 25–49, 50–64, 65–74 or 75+). These age categories are wider among younger (lower risk) age groups and narrower among older (higher risk) age groups, in an attempt to reflect the strong increase in risk of postoperative death with increasing age. Patient sex was defined at the time of the procedure and categorised as either male or female, with sex data missing for 18 admissions and procedure-days (<0.001% of admissions and total procedures). Ethnicity was defined using prioritised ethnicity at the time of the admission from NMDS data and categorised as either Māori, Pacific, Asian, European or Middle Eastern/Latin American/African/Other (hereafter referred to as MELAA/Other).<sup>29</sup> Ethnicity data were sourced from NMDS, which is guided by ethnicity data protocols, where ethnicity is ideally self-identified by the patient.

Patient deprivation at the time of procedure was determined using New Zealand's 2013 Deprivation Index (NZDep), which uses an individual's residential address to define area deprivation.<sup>30</sup> NZDep deciles were collapsed into quintiles from 1 (least deprived) to 5 (most deprived). To determine NZDep, the domicile in which an individual lived at the time of the procedure was mapped to its respective 2013 Census Area Unit (CAU). In cases where domicile codes could not be mapped to the 2013 CAU due to changes in CAU definition between the 2006 and 2013 Census (n=1 63 079 or 5.2% of admissions), NZDep score and Urban/Rural Profile Classification (URPC) were determined using the 2006 mapping. Missing data prevented attribution of NZDep for 51 151 admissions or 53 559 procedures (1.7% of the total procedures). Patient rurality was defined using a modified version of the URPC,<sup>31</sup> with the area where patient lived at the time of the procedure classified as urban (main urban area + satellite urban area), independent urban or

rural. Missing data prevented attribution of rurality for 53 486 admissions or 55 999 procedures (1.7% of the total procedures). There is an overlap between missingness of deprivation and rurality data, driven by missing CAU data.

Patient comorbidity was defined using the M3 Index.<sup>32</sup> For each patient, NMDS data from the 5-year period prior to the date of admission for the given procedure were searched for the presence of any of the 61 conditions included in the M3 Index using ICD-10 codes. Each condition was coded as either present or not present (1 if present, 0 if not present), and each condition was then weighted according to its relationship with mortality in the general population (see Stanley and Sarfati<sup>32</sup> for weights and more information about the M3 Index). Condition weights were then summed for each patient at their admission to give their M3 Index score. For descriptive analysis, M3 scores were categorised as 0, >0–1, >1–2, >2–3 or 3+, with higher score indicating greater comorbidity. For regression models, M3 score was included as a splined variable,<sup>32</sup> with knots placed at the 0th, 90th and 95th percentiles.<sup>33</sup> ASA physical status score was determined from ICD anaesthesia codes and categorised as either 1–2, 3, 4–5 or unknown.<sup>16</sup> In those instances where more than one ASA score was coded on a given procedure-day, a give-way rule was applied wherein the worst, ASA score was retained for that procedure-day.

All procedures were assigned an admission type depending on the reason for their hospital admission, with admission type categorised as either acute or elective/waiting list. Postoperative mortality was defined as death from any cause recorded within either 30 or 90 days of that procedure, inclusive of the date of procedure.

### Statistical analysis

Descriptive analyses included crude counts and rates (per 100 procedures) of 30-day and 90-day mortality. When investigating rates of 30-day mortality (including temporal trends), we age-standardised rate data to the age structure of those who underwent a procedure in 2010 (separately for both acute and elective/waiting list procedures), in order to account for changes in population age structure over time. To test for notable increases or decreases in the rate of postoperative death over time, we calculated a two-sided Cochran-Armitage test for trend.<sup>34</sup> As part of the temporal trend analysis, we also explored the absolute rate of both acute and elective/waiting list procedures performed on New Zealanders, using the Statistics New Zealand estimated residential population for each of the years in the study period (2005–2017) as the denominator (online supplemental material 1).<sup>35</sup>

In order to establish the relationship between our measured covariates and risk of 30-day mortality, we conducted Cox proportional hazards regression modelling. Within the Cox model, we censored procedures when either (a) no death occurred within 30 days of the procedure or (b) if a subsequent procedure occurred within a 30-day period from the date of the original procedure.<sup>36</sup> As such, for those who had multiple procedures within a

given 30-day period, the last procedure (rather than the first) was used as the index procedure (see online supplemental material 2 and online supplemental material 2 table for further detail). A total of 2960 individuals who died within 30 days of a procedure had had at least one other previous procedure within the 30-day period prior to death (18% of all deaths within 30 days). HRs and their 95% CIs were determined for the risk of 30-day mortality for each modelled variable (procedure type, procedure risk, age, sex, ethnicity, deprivation, rurality, M3 score, ASA score), giving the risk for each variable adjusted for all other covariates in the model.

Data management and analysis were performed in SAS V.9.4 (SAS Institute) and Microsoft Excel V.2016 (Microsoft Corporation, USA). The data used for the analysis in this study are available on request from the New Zealand Ministry of Health for eligible research groups (Ministry of Health data extract number 2018-0452).

### Patient and public involvement

The development of our study objectives was informed by the need to monitor population-level rates of postoperative mortality and in particular assess how these rates differ within the population. However, patients were not directly involved in the study.

### RESULTS

A total of 1 836 683 unique patients accounted for 3 117 374 admissions in which a procedure was performed under general anaesthetic over the study period. Since only 2% of admissions had more than one procedure-day where a general anaesthetic was administered, we finished with a total of 3 217 823 unique procedure-days. Rates of 30-day and 90-day mortality following a procedure under general anaesthetic are shown in table 1 and online supplemental material 3 respectively, stratified by covariates. Results from the multivariate Cox regression models are shown in table 2.

In total, of the 3 271 823 procedures performed under general anaesthetic over the study period, a total of 16 630 patients died within 30 days (crude rate: 0.5 per 100 procedures) and 28 488 died within 90 days (0.9 per 100). Of the 780 009 acute procedures performed over the study period, a total of 12 220 patients died within 30 days of their procedure (crude rate: 1.6 per 100). When stratified by procedure specialty, the highest rate of 30-day mortality following acute procedures was observed for respiratory system procedures (age-standardised rate: 6.3 per 100), followed by neurosurgery (3.6 per 100), cardiovascular (3.3 per 100), digestive system (2.1 per 100), urinary system (1.4 per 100), musculoskeletal (1.0 per 100) and other procedures (0.6 per 100).

Of the 2 437 814 elective/waiting list procedures, a total of 4410 patients died within 30 days (0.2 per 100 procedures). The highest rate of 30-day mortality following elective/waiting list procedures was again observed for respiratory system procedures (age-standardised rate:

**Table 1** Postoperative mortality within 30 days of an acute and elective/waiting list procedure performed under general anaesthetic, for the total population and by demographic subgroup

	Acute				Elective/waiting list			
	Procedures	Deaths	Death rate (n/100)		Procedures	Deaths	Death rate (n/100)	
	n	n	Crude	Age standardised (95% CI)	n	n	Crude	Age standardised (95% CI)
Total procedures	780 009	12 220	1.6	–	2 437 814	4410	0.2	–
Procedure specialty								
Cardiovascular	35 055	1560	4.5	3.3 (3.2 to 3.5)	97 199	924	1	0.7 (0.6 to 0.7)
Digestive system	185 469	4185	2.3	2.1 (2 to 2.2)	381 443	1523	0.4	0.3 (0.3 to 0.3)
Respiratory system	12 089	723	6	6.3 (6.1 to 6.5)	30 557	377	1.2	1 (1 to 1.1)
Neurosurgery	28 243	1101	3.9	3.6 (3.5 to 3.8)	66 445	255	0.4	0.4 (0.4 to 0.4)
Musculoskeletal	268 160	3449	1.3	1 (0.9 to 1.1)	585 997	504	0.1	0.1 (0.1 to 0.1)
Urinary system	19 105	369	1.9	1.4 (1.3 to 1.5)	102 059	264	0.3	0.2 (0.1 to 0.2)
Other	231 888	833	0.4	0.6 (0.6 to 0.7)	1 174 114	563	0	0.1 (0.1 to 0.1)
Procedure risk								
1 (lowest risk)	140 320	776	0.6	0.8 (0.7 to 0.8)	464 542	263	0.1	0.1 (0.1 to 0.1)
2	310 735	2032	0.7	0.9 (0.8 to 1)	1 252 395	1001	0.1	0.1 (0.1 to 0.1)
3	238 087	3817	1.6	1.2 (1.1 to 1.3)	503 548	668	0.1	0.1 (0.1 to 0.1)
4	63 632	3943	6.2	4 (3.8 to 4.1)	164 375	1586	1	0.6 (0.6 to 0.7)
5 (highest risk)	27 235	1652	6.1	5.1 (4.9 to 5.3)	52 954	892	1.7	1.2 (1.2 to 1.3)
Age (years)								
<25	260 373	609	0.2	–	687 778	210	0	–
25–49	243 794	1015	0.4	–	715 463	322	0	–
50–64	120 772	1927	1.6	–	541 829	844	0.2	–
65–74	69 109	2462	3.6	–	300 342	1150	0.4	–
75+	85 961	6207	7.2	–	192 402	1884	1	–
Sex								
Female	361 641	5891	1.6	1.4 (1.4 to 1.5)	1 301 351	1895	0.1	0.2 (0.1 to 0.2)
Male	418 367	6329	1.5	1.6 (1.5 to 1.7)	1 136 446	2515	0.2	0.2 (0.2 to 0.2)
Ethnicity								
Māori	148 464	1499	1	2.1 (2 to 2.2)	305 879	585	0.2	0.4 (0.4 to 0.4)
Pacific	64 403	569	0.9	1.6 (1.5 to 1.7)	113 784	168	0.1	0.3 (0.3 to 0.3)
Asian	36 299	429	1.2	1.7 (1.6 to 1.8)	117 084	107	0.1	0.2 (0.1 to 0.2)
European	507 878	9411	1.9	1.4 (1.3 to 1.5)	1 777 708	3417	0.2	0.2 (0.1 to 0.2)
MELAA/Other	22 965	312	1.4	1.4 (1.3 to 1.5)	123 359	133	0.1	0.1 (0.1 to 0.1)
Deprivation (NZDep Decile)								
1–2	112 029	1544	1.4	1.3 (1.2 to 1.4)	450 239	527	0.1	0.1 (0.1 to 0.1)
3–4	118 095	1716	1.5	1.3 (1.2 to 1.4)	427 068	610	0.1	0.1 (0.1 to 0.2)
5–6	140 104	2384	1.7	1.5 (1.4 to 1.6)	475 398	874	0.2	0.2 (0.1 to 0.2)
7–8	171 830	3063	1.8	1.6 (1.5 to 1.7)	526 368	1136	0.2	0.2 (0.2 to 0.2)
9–10	222 015	3291	1.5	1.8 (1.7 to 1.9)	521 118	1195	0.2	0.3 (0.2 to 0.3)
Rurality								
Urban	580 028	9011	1.6	1.5 (1.4 to 1.6)	1 758 564	3006	0.2	0.2 (0.2 to 0.2)
Independent urban	90 224	1867	2.1	1.7 (1.6 to 1.9)	317 170	852	0.3	0.2 (0.2 to 0.2)
Rural	93 287	1117	1.2	1.3 (1.2 to 1.4)	322 551	480	0.1	0.2 (0.1 to 0.2)
Comorbidity (M3 Index category)								
0	494 470	1618	0.3	0.6 (0.6 to 0.7)	1 753 031	428	0	0 (0 to 0)

Continued

Table 1 Continued

	Acute				Elective/waiting list			
	Procedures	Deaths	Death rate (n/100)		Procedures	Deaths	Death rate (n/100)	
	n	n	Crude	Age standardised (95% CI)	n	n	Crude	Age standardised (95% CI)
>0-1	196780	4516	2.3	1.6 (1.5 to 1.7)	494940	1591	0.3	0.2 (0.2 to 0.2)
>1-2	57886	3293	5.7	3.2 (3.1 to 3.4)	123863	1201	1	0.7 (0.6 to 0.7)
>2-3	24165	2049	8.5	5.6 (5.4 to 5.8)	54042	902	1.7	1.2 (1.1 to 1.2)
≥3	6708	744	11.1	7 (6.7 to 7.2)	11938	288	2.4	1.7 (1.7 to 1.8)
ASA score								
1-2	484622	716	0.1	0.3 (0.2 to 0.3)	1122776	481	0	0.1 (0 to 0.1)
3	115815	3544	3.1	1.7 (1.6 to 1.9)	226284	1565	0.7	0.4 (0.4 to 0.5)
4-5	37847	5450	14.4	10.4 (10.1 to 10.7)	25978	1313	5.1	3.8 (3.7 to 3.8)
Not recorded	141725	2510	1.8	1.8 (1.7 to 1.9)	1062776	1051	0.1	0.1 (0.1 to 0.1)

MELAA, Middle Eastern/Latin American/African.

1.0 per 100), followed by cardiovascular (0.7 per 100), neurosurgery (0.4 per 100), digestive system (0.3 per 100), urinary system (0.2 per 100), musculoskeletal (0.1 per 100) and other procedures (0.1 per 100). Over 90 days, the number of deaths following an acute procedure increased to 19326 (2.5 per 100) and the number of deaths following elective/waiting list procedure increased to 9162 (0.4 per 100). 90-day trends in terms of procedure specialty remained similar to those observed at 30 days.

Temporal trends in 30-day mortality are shown in [figure 1](#) for all combined procedures, while [figure 2](#) shows 30-day mortality stratified by procedure specialty and risk (statistical tests for trend (p values) are shown in online supplemental material 4). Total rates of 30-day mortality appeared to decline over the study period, for both acute (p for trend=0.097) and elective/waiting list (p for trend <0.001) procedures ([figure 1](#)), though the statistical evidence was less robust for acute procedures. When stratified by procedure specialty ([figure 2](#)), we observed some evidence of improvements over time in 30-day mortality for some specialties, particularly both acute and elective/waiting list digestive system procedures (both p for trend <0.01). However, trends were somewhat erratic for those specialties with low absolute numbers of deaths (such as respiratory and urinary procedures), and so results should be interpreted with caution for these procedures. Rates of 30-day mortality following cardiovascular procedures appeared relatively stable over time (p for trend: acute procedures 0.45; elective/waiting list procedures 0.91). When stratified by procedure risk, we observed an apparent improvement in postoperative mortality over time particularly for the higher risk procedures (eg, elective/waiting list procedures, procedure risk 5: p for trend <0.01).

The rate of postoperative mortality increased with age for both acute and elective/waiting list procedures: after adjusting for all other covariates within the Cox regression models (including sex, ethnicity, deprivation, rurality,

comorbidity, ASA score, procedure specialty and procedure risk), there remained a clear relationship between increasing age and risk of death within 30 days of an acute or elective/waiting list procedure (eg, adjusted HR of 30-day mortality following an acute procedure, <25 years: reference group; 75+years: 6.98, 95% CI 6.36 to 7.70). There was no evidence of strong disparities in postoperative mortality between men and women. Once adjusted for the included covariates, disparities in postoperative mortality for other ethnic groups compared with Europeans largely disappeared for acute procedures; however, Māori patients were 30% more likely to die within 30 days of an elective/waiting list procedure than European patients (1.32, 95% CI 1.20 to 1.50), while Pacific (0.93, 95% CI 0.79 to 1.10), Asian (0.85, 95% CI 0.70 to 1.00) and MELAA/Other (1.06, 95% CI 0.89 to 1.30) patients appeared no more or less likely. Once adjusted for other covariates, there remained a pronounced risk gradient for elective/waiting list procedures with increasing deprivation (NZDep deciles 1-2 reference group; NZDep deciles 9-10 1.33, 95% CI 1.19 to 1.50). Those living in rural areas appeared to have a similar rate of postoperative death within 30 or 90 days of a procedure compared with those living in urban areas.

Patients with a high comorbidity burden had a substantially higher rate of death within 30 or 90 days of an acute or elective/waiting list procedure; for example, those with an M3 Index score of 3 (indicating high comorbidity burden) were more than three times more likely to die within 30 days of an acute procedure than those with a comorbidity score of zero (adjusted HR 3.19, 3.01-3.40) and 10 times more likely to die within 30 days of an elective/waiting list procedure (10.08, 95% CI 9.75 to 12.00). Those with an ASA score of 4-5 were more than 20 times more likely to die within 30 days of an acute procedure than those with an ASA score of 1-2 (21.14, 95% CI 19.39 to 23.00) and nearly 15 times more likely following an elective/waiting list procedure (14.73, 95% CI 13.12

**Table 2** Comparison between subgroups of the adjusted likelihood of death within 30 days of an acute and elective/waiting list procedure

	Acute		Elective/waiting list	
	Crude HR	Adjusted HR (95% CI)	Crude HR	Adjusted HR (95% CI)
<b>Procedure specialty</b>				
Cardiovascular	Ref	Ref	Ref	Ref
Digestive system	0.93 (0.87–1)	1.32 (1.23 to 1.4)	0.88 (0.8–1)	1.49 (1.35 to 1.7)
Respiratory system	1.64 (1.51–1.8)	2.33 (2.12 to 2.5)	1.56 (1.39–1.8)	1.66 (1.46 to 1.9)
Neurosurgery	0.96 (0.89–1)	2.29 (2.12 to 2.5)	0.63 (0.55–0.7)	1.9 (1.64 to 2.2)
Musculoskeletal	0.78 (0.72–0.8)	0.91 (0.85 to 1)	0.27 (0.23–0.3)	0.75 (0.66 to 0.9)
Urinary system	1.38 (1.22–1.6)	1.09 (0.96 to 1.2)	0.86 (0.74–1)	0.76 (0.65 to 0.9)
Other	0.4 (0.36–0.4)	0.55 (0.49 to 0.6)	0.2 (0.18–0.2)	0.56 (0.49 to 0.6)
<b>Procedure risk</b>				
1 (lowest risk)	Ref	Ref	Ref	Ref
2	1.18 (1.09–1.3)	0.83 (0.75 to 0.9)	1.41 (1.23–1.6)	1.08 (0.94 to 1.2)
3	2.91 (2.7–3.1)	1.03 (0.93 to 1.1)	2.34 (2.03–2.7)	1.24 (1.06 to 1.4)
4	11.57 (10.71–12.5)	1.67 (1.5 to 1.9)	17.13 (15.03–19.5)	2.6 (2.24 to 3)
5 (highest risk)	11.32 (10.39–12.3)	1.12 (0.99 to 1.3)	30.03 (26.17–34.5)	2.21 (1.87 to 2.6)
<b>Age (years)</b>				
<25	Ref	Ref	Ref	Ref
25–49	1.78 (1.61–2)	1.48 (1.34 to 1.6)	1.47 (1.24–1.8)	1.15 (0.96 to 1.4)
50–64	6.87 (6.27–7.5)	2.59 (2.35 to 2.8)	5.11 (4.39–5.9)	2.05 (1.75 to 2.4)
65–74	15.49 (14.17–16.9)	3.94 (3.58 to 4.3)	12.56 (10.84–14.6)	3.12 (2.67 to 3.7)
75+	31.87 (29.32–34.6)	6.98 (6.36 to 7.7)	32.22 (27.93–37.2)	5.86 (5.01 to 6.8)
<b>Sex</b>				
Female	Ref	Ref	Ref	Ref
Male	0.93 (0.9–1)	0.96 (0.93 to 1)	1.52 (1.43–1.6)	1.03 (0.97 to 1.1)
<b>Ethnicity</b>				
Māori	0.54 (0.51–0.6)	1.08 (1.02 to 1.2)	1 (0.91–1.1)	1.32 (1.2 to 1.5)
Pacific	0.48 (0.44–0.5)	0.96 (0.88 to 1)	0.77 (0.66–0.9)	0.93 (0.79 to 1.1)
Asian	0.64 (0.58–0.7)	1.08 (0.98 to 1.2)	0.48 (0.39–0.6)	0.85 (0.7 to 1)
European	Ref	Ref	Ref	Ref
MELAA/Other	0.73 (0.65–0.8)	1.11 (0.99 to 1.3)	0.56 (0.47–0.7)	1.06 (0.89 to 1.3)
<b>Deprivation (NZDep Decile)</b>				
1–2	Ref	Ref	Ref	Ref
3–4	1.06 (0.99–1.1)	1 (0.93 to 1.1)	1.22 (1.09–1.4)	1.08 (0.96 to 1.2)
5–6	1.24 (1.16–1.3)	1.07 (1 to 1.1)	1.57 (1.41–1.8)	1.2 (1.08 to 1.3)
7–8	1.3 (1.22–1.4)	1.1 (1.03 to 1.2)	1.85 (1.66–2)	1.28 (1.15 to 1.4)
9–10	1.08 (1.01–1.1)	1.13 (1.06 to 1.2)	1.96 (1.77–2.2)	1.33 (1.19 to 1.5)
<b>Rurality</b>				
Urban	Ref	Ref	Ref	Ref
Independent urban	1.34 (1.27–1.4)	1.07 (1.02 to 1.1)	1.57 (1.46–1.7)	1.23 (1.13 to 1.3)
Rural	0.77 (0.72–0.8)	0.97 (0.91 to 1)	0.87 (0.79–1)	1.04 (0.94 to 1.1)
<b>Comorbidity (M3 Index score)</b>				
0	Ref	Ref	Ref	Ref
1	11.06 (10.54–11.6)	1.94 (1.83 to 2.1)	22.37 (20.53–24.4)	6.1 (5.51 to 6.8)
2	15.69 (15–16.4)	2.52 (2.39 to 2.7)	35.26 (32.61–38.1)	8.43 (7.66 to 9.3)
3	20.06 (19.05–21.1)	3.19 (3.01 to 3.4)	48.66 (44.57–53.1)	10.8 (9.75 to 12)

Continued

Table 2 Continued

	Acute		Elective/waiting list	
	Crude HR	Adjusted HR (95% CI)	Crude HR	Adjusted HR (95% CI)
ASA score				
1–2	Ref	Ref	Ref	Ref
3	20.95 (19.33–22.7)	5.48 (5.03 to 6)	16.19 (14.62–17.9)	3.33 (2.99 to 3.7)
4–5	105.67 (97.75–114.2)	21.14 (19.39 to 23)	121.46 (109.41–134.8)	14.73 (13.12 to 16.5)
Not recorded	12.09 (11.13–13.1)	7.39 (6.78 to 8.1)	2.31 (2.07–2.6)	2.45 (2.19 to 2.7)

1=adjusted for all other covariates.

MELAA, Middle Eastern/Latin American/African.

to 16.50), even after adjusting for comorbidity (and all other covariates).

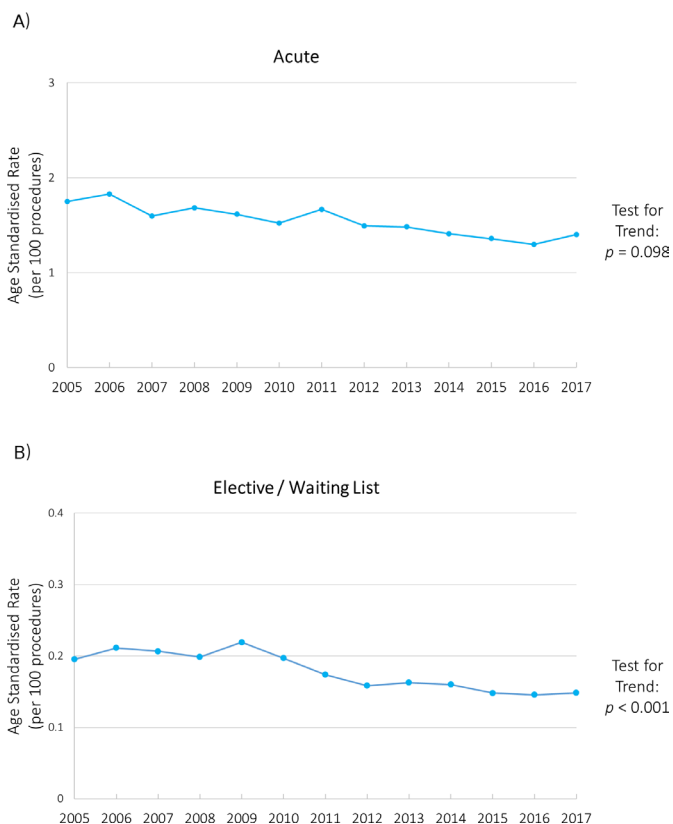
Risk of postoperative mortality increased with increasing prespecified procedure risk; once adjusted for covariates, the increase between adjacent procedure risk categories became less obvious for acute procedures, but remained for elective/waiting list procedures (eg, procedure risk category 1: reference group; procedure risk category 5: adjusted HR 2.21, 95% CI 1.87 to 2.60). Compared with cardiovascular procedures, and once adjusted for covariates, respiratory procedures, digestive system procedures and neurosurgery had higher risk of death following either acute or elective/waiting list procedures (eg, acute procedures: adjusted HRs 1.3–2.3), while musculoskeletal

and urinary system procedures had a lower or similar risk of death (adjusted HRs 0.9–1.1). However, it should be noted that the selection of a reference group for this procedure-based analysis was arbitrary.

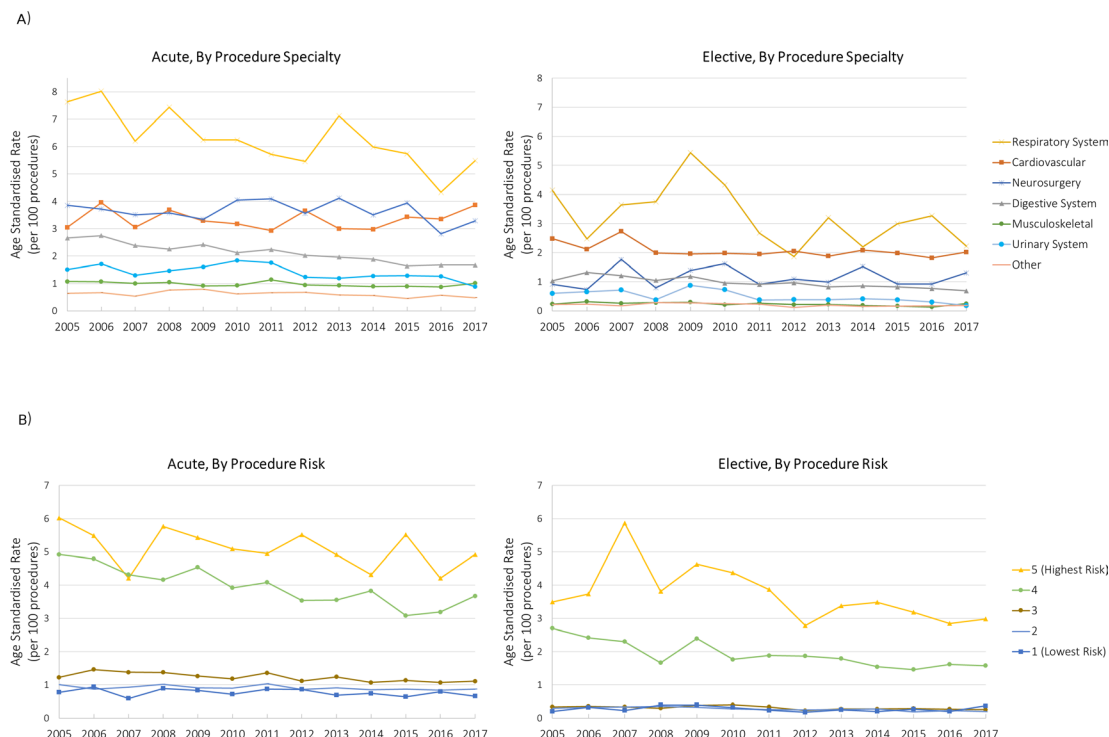
## DISCUSSION

Using national-level data, we observed a 30-day mortality rate following any procedure under general anaesthetic of 0.5 per 100 procedures. A similar study in Scotland observed an in-hospital mortality rate of 0.46 per 100 procedures when examining all surgical procedures (regardless of anaesthetic type) conducted in 2014.<sup>37</sup> We observed that postoperative death with 30 days of a procedure is much more likely following acute (1.6 per 100 procedures) than elective/waiting list procedures (0.2 per 100), which is a reflection of the emergency nature of the procedure among those admitted acutely, which will include instability of the condition of the patient. These rates are comparable to those observed in a recent study from the USA,<sup>38</sup> and the acute versus elective/waiting list trend has been consistently observed worldwide, with a 28-country European study showing that in-hospital death is more than three times as likely following an acute procedure compared with an elective one.<sup>39</sup>

In absolute terms, the procedure specialty with the highest number of postoperative death was digestive system procedures, followed by musculoskeletal and cardiovascular procedures (largely driven by volumes of patients undergoing these procedures). However, considered as risk per 100 operations, respiratory procedures had the highest rates of postoperative death following either acute (6 per 100) or elective/waiting list (1 per 100) procedures, although these rates varied erratically over time (see the Temporal trends below). These rates are somewhat similar to other reports: a Norwegian study on postoperative mortality following lung cancer resection observed a 30-day mortality rate of 4 per 100 procedures,<sup>40</sup> while an international study of select centres in 14 countries observed a 30-day mortality rate of 1.7 per 100 following any thoracic surgery. These earlier studies were not stratified by admission type.



**Figure 1** Age-standardised temporal trends in 30-day mortality among those undergoing (A) acute or (B) elective/waiting list procedures under general anaesthetic.



**Figure 2** Age-standardised temporal trends 30-day mortality among those undergoing acute or elective/waiting list procedures under general anaesthetic, by (A) procedure specialty and (B) procedure risk. Rate data, confidence limits and tests for trend (p values) are shown in online supplemental material 4.

### Temporal trends

We observed that the rate of postoperative mortality appears to have reduced over time for both acute and elective/waiting list procedures (figure 1, standardised by age). When stratified by procedure specialty (figure 2), we observed substantial reductions in postoperative death for several specialties (particularly digestive system procedures), but no apparent change for others including cardiovascular procedures. This general reduction in postoperative mortality is consistent with that observed in England between 1998 and 2013, as is the observation that rates of postoperative death following cardiovascular (particularly cardiac) procedures have remained stable over time.<sup>41</sup> Other studies examining specific procedures have noted improvements over time for several procedure types<sup>42–44</sup> including digestive system procedures.<sup>43</sup>

The drivers behind these improvements are likely to be multifactorial, but in the New Zealand context, they may include improvements in surgical standard setting by central government and relevant clinical governance bodies (eg, the Royal Australasian College of Surgeons). Specifically, it is possible that temporal improvements may reflect heightened preoperative multidisciplinary input, particularly in high risk patients, improved preoperative health optimisation (including prehabilitation) and improved identification of high risk patients with preassessment clinics. In Scotland, a 37% reduction in in-hospital death following surgery was observed after the introduction of the WHO Surgical Safety Checklist as part of the Scottish Patient Safety Programme.<sup>37</sup> Nepogodiev and colleagues noted a similar improvement following the introduction of the checklist in England.<sup>41</sup> In

New Zealand, intraoperative factors that may have improved over the study period include initiatives like surgical checklists and the availability of Networkz (a national in situ training programme for surgical teams). Improvements in postoperative factors include increased standardisation of postoperative care through programmes like the enhanced recovery after surgery and End PJ Paralysis programmes.<sup>45</sup>

However, the observed decline may not be entirely due to changes in the quality of perioperative care: other contributing factors could include increased volumes of procedures on lower risk populations and/or a restriction on access to surgery among higher risk populations. Further work is required to unpick the true drivers of this apparent gradual decline.

### Risk factors

After adjusting for all other covariates, including procedure specialty, we observed that risk of postoperative death was strongly related to increasing age, indigenous Māori ethnicity, high levels of deprivation and increasing comorbidity and ASA levels, and the risk of the procedure itself. Pooling data from 500 hospitals across 28 European countries, Pearse *et al*<sup>39</sup> similarly observed that risk of in-hospital death following surgery was strongly related to increasing age, increasing ASA score, increasing grade of surgery (broadly comparable to procedure risk) and the presence of substantial comorbidities. The lack of a rural effect—where those in rural areas appear no more likely to die than those in urban areas—has been observed before in other procedure-specific studies in New Zealand.<sup>46</sup>



In keeping with previous observations,<sup>16,47</sup> we found that Māori patients tend to be more likely to die within 30 days of a procedure than other ethnic groups, including Pacific patients. We previously observed that Māori patients (but not Pacific patients) with diabetes were nearly 50% more likely to die within 30 days of a major lower limb amputation than European patients with diabetes—even after adjusting for differences in age, sex, deprivation, rurality, hospital volume, admission type and comorbidity.<sup>5</sup> This suggests that the higher risk of postoperative mortality for Maori patients is in part due to institutionalised racism in the healthcare system,<sup>48,49</sup> where Maori patients are meeting barriers to geographically, financially and culturally accessible best practice care along the clinical pathway,<sup>50</sup> including access to specialist surgeons and surgical teams.<sup>51</sup> These observations are in keeping with other international evidence of inequities in postoperative mortality for minority racial/ethnic groups<sup>52–54</sup>; for example, a recent meta-analysis focussing on racial differences in coronary artery bypass graft procedures found that compared with white patients, black patients had a 25% increased risk of death in hospital when adjusted for both patient-level and hospital-level factors (OR 1.25, 95% CI 1.13 to 1.39).<sup>55</sup>

The strong relationship observed between risk of death and patient comorbidity (and ASA level) is consistent with other large cohort studies.<sup>39</sup> The most straightforward explanation is that those with comorbidity are more likely to have complications and/or die shortly after surgery because they are simply sicker than those without comorbidity; however, this relationship is also likely to be influenced by procedure type within specialties (although the latter should have been largely accounted for when adjusting for procedure risk within our Cox models). While increasing levels of comorbidity likely necessitate increasing surgical intervention, it is also worth noting that high-risk procedures might not be offered to some patients with severe comorbidity for the perceived risk of causing more harm than benefit.<sup>56</sup>

A key strength of this study is the national and temporal coverage of the surgical cohort and outcome data. New Zealand has universal healthcare, and as such most procedures are publicly funded<sup>57,58</sup>; however, we also augmented our analysis to include those private hospitals that report data to the national collections. In addition, the data linkage available in New Zealand means that we were able to follow patients beyond their discharge from hospital, in order to measure 30-day and 90-day mortality outcomes. There are few other international contexts able to conduct such national studies with the existing routine data.<sup>16</sup>

We decided to focus exclusively on procedures performed under general anaesthesia rather than including neuraxial block and/or regional anaesthesia. The primary purpose for this was to account for the insult of the general anaesthesia itself as part of the risk of postoperative mortality. We acknowledge that some key procedures are performed under both general anaesthetic and

neuraxial/regional block, and that selection of anaesthetic will be patterned by some of the key variables investigated in this study (including age and comorbidity). A comparison of postoperative mortality outcomes between procedures commonly performed under either general anaesthesia or neuraxial/regional block is currently underway. Due to data limitations, it was not possible in our study to adequately investigate the role of hospital volume or clustering of patients at a hospital level.

## CONCLUSION

The rate of postoperative death following an acute or elective/waiting list procedure in New Zealand is similar to that observed in other developed countries. However, as in other contexts, we observed that the likelihood of postoperative death was not proportionally distributed within our population: older patients, Māori patients, those living in areas with higher deprivation and those with comorbidity are at increased risk of postoperative death, even after adjusting for all available factors that might explain differences within these groups. Increasing surgical risk of the procedure being performed was also associated with an increased risk of postoperative death. Encouragingly, it appears that the risk of postoperative mortality has declined over the past decade, possibly reflecting improvements in perioperative quality of care; however, this decline did not occur equally across all procedure specialties.

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