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# Retrospective review of abdominal aortic aneurysm deaths in New Zealand: what proportion of deaths is potentially preventable by a screening programme in the contemporary setting?

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## ABSTRACT

**Objectives** To describe the proportions of people dying from abdominal aortic aneurysm (AAA) who might have benefited from a formal screening programme for AAA.

**Design** Retrospective cross-sectional review of deaths.

**Setting and study populations** All AAA deaths registered in New Zealand from 2010 to 2014 in the absence of a national AAA screening programme.

**Main outcome measures** Known history of AAA prior to the acute event leading to AAA death, prognosis limiting comorbidities, history of prior abdominal imaging and a validated multimorbidity measure (M3-index scores).

**Results** 1094 AAA deaths were registered in the 5 years between 2010 and 2014 in New Zealand. Prior to the acute AAA event resulting in death, 31.3% of the cohort had a known AAA diagnosis, and 10.9% had a previous AAA procedure. On average, the AAA diagnosis was known 3.7 years prior to death. At least 77% of the people dying from AAA also had one or more other prognosis limiting diagnosis. The hazard of 1-year mortality associated with the non-AAA related comorbidities for the AAA cohort aged 65 or above were 1.5–2.6 times higher than to the age matched general population based on M3-index scores. In 2014, overall AAA deaths accounted for only 0.7% of total deaths, and 1.0% of deaths among men aged 65 or above in New Zealand. At most, 20% of people dying from AAA in New Zealand between 2010 and 2014 might have had the potential to derive full benefit from a screening programme. About 51% of cases would have derived no or very limited benefit from a screening programme.

**Conclusion** Falling AAA mortality, and high prevalence of competing comorbidities and/or prior AAA diagnosis and procedure raises the question about the likely value of a national AAA screening programme in a country such as New Zealand.

## Strengths and limitations of this study

- A retrospective review of abdominal aortic aneurysm (AAA) deaths in a country is a key component in evaluating the potential impact of a screening programme.
- This study provides a systematic method of/for describing multimorbidities of people who died from AAA in New Zealand.
- The disease definitions of this study are based on the International Classification of Diseases 10th Revision which are widely used internationally.
- The record linkages were carried out consistently using national unique identifiers for each individual.
- The percentage of prior abdominal aorta imaging is likely to be significantly underestimated because imaging scans in the community are not captured in coding routinely.

## INTRODUCTION

There has been increasing scrutiny in reviewing the balance between benefits and harms of screening programme. Screening for abdominal aortic aneurysm (AAA) is a contested topic,[1 2] and the approach to population level screening is highly variable between different countries internationally.[3] There are well established national screening programme for AAA in the UK and Sweden.[4 5] The US Preventive Services Task Force and the Canadian Task Force on Preventive Health Care recommend one-time screening with ultrasonography for AAA for men who have ever smoked (from ages 65 to 75 years and from 65 to 80, respectively).[6 7] On the other hand, many other high-income countries such as Australia and New Zealand have yet to establish a national screening programme.[8 9]

Many evaluations of AAA screening programme predominately focus on case detection and process measures without formally undertaking linkage study to examine the likely impact from the AAA screening programme on overall mortality at a population level in the contemporary setting.[10 11] While rapidly falling AAA prevalence and mortality prior to commencement of AAA screening in UK were acknowledged

as important considerations in regard to cost effectiveness of a AAA screening programme,[12–14] there has been less scrutiny on whether the rapidly evolving epidemiology has been captured appropriately in cost effectiveness studies that inform policy and commentaries.[15–17]

This study aims to design a method to review AAA deaths, using national data from New Zealand as an example, that can be replicable internationally to provide information on the potential value of a formal national AAA screening programme.

### Study aims to quantify the following

1. The proportion of total deaths caused by AAA in New Zealand, and England and Wales from publicly available national mortality data, including a subgroup of men aged 65 and over which is a target population for screening in some countries.
   Out of the deaths caused by AAA in New Zealand.
2. The proportion of AAA deaths that are highly unlikely to be prevented by AAA screening programme (eg, AAA diagnosis is known before the index event of AAA death, people who had received a prior imaging of the abdomen, people who already had prior AAA surgery).
3. The prevalence of competing comorbidities:
   a. The proportion if AAA deaths were prevented, healthy life years would not be substantially prolonged (ie, people who had other prognosis limiting comorbidities).
   b. The proportion who had other comorbidities that would likely impact on survival and/or quality of life and/or peri-operative complexity and costs.
4. The proportion of people who may have significant life years potentially gained by a AAA screening programme.

## METHODS

### Data sources

The following routine administrative datasets were sourced from the Analytical Services team from the New Zealand Ministry of Health:

- National Mortality Collection.
- National Minimum Dataset (Inpatients).
- New Zealand Cancer Registry.

All health service users in New Zealand are assigned a National Health Index (NHI). In this study the administrative data listed above are linked by an encrypted form of NHI, anonymously, at an individual level.

Deaths caused by AAA are identified from the National Mortality collection in New Zealand by the following International Statistical Classification of Diseases and Related Health Problems Codes, Tenth Revision (International Classification of Diseases (ICD) 10 codes): (I71.3, I74.4, I71.5, I71.6, I71.8, I71.9) from 2010 to 2014. The AAA deaths are analysed by age bands, gender, ethnicity and NZDep2013 Index of Deprivation. NZDep2013 is a relative geographical measure of socioeconomic deprivation, based on eight dimensions of deprivation, including income, employment, education qualifications, home ownership, household living space, access to car and communications, and family structure.[18]

The prior clinical diagnoses and imaging studies are identified by the hospitalisation events recorded in the National Minimum Datasets, or in the New Zealand Cancer Registry.

Any acute AAA hospital event with a discharge date that is within 2 days of the date of death from AAA are not included in the analyses because the diagnoses and comorbidities could potentially be complications related to the acute AAA presentation resulting in death.

If there are any prior continuous events that ended with a discharge date within 2 days of date of death and the event is coded as acute ('AC'), and has any AAA diagnosis (regardless of ruptured or not) at the same event, that is, ICD 10 codes I71.3–I71.9, then the event is excluded from the morbidity and prior imaging analyses. If there are any prior continuous events that with a discharge date within 2 days of date of death, and the event is coded as elective or arranged hospital event ('WN' or 'AA'), and has an AAA ruptured diagnosis for that event (ie, I71.3, I71.5, I71.8), then these events are excluded from the morbidity and prior imaging analyses, otherwise these events are included as part of the comorbidities analyses and calculation.

Prior morbidities and imaging studies in the last 15 years were arranged into five categories: A to E, with 24 diagnostic or medical history groupings are described below (detailed definitions are listed in online supplementary information).

#### A: Groups already identified with no or very little benefit to accrue from a national AAA screening programme

1. AAA diagnosis is known prior to death event in the absence of a formal screening programme.
2. Previous abdominal aortic intervention or surgery.
3. Previous abdominal ultrasound, CT scan or MRI in hospital (and hence these people are less likely to benefit from one-time screening).

#### B: Diagnoses that are strongly associated with poor prognosis—likely little benefit if any would accrue from screening

1. Palliative care codes.
2. Metastatic cancer (from either cancer registry or NMDS).[19–21]
3. Upper gastrointestinal cancers.[19–21]
4. Lung cancer including mesothelioma.[19–21]
5. Respiratory failure.[19 20]
6. Heart failure (including cor-pulmonale and cardiomyopathy).[19–21]
7. Cirrhosis and gastro-oesophageal varices.[19–21]

#### C: Diagnoses that would reduce life span and/or increase perioperative and postoperative complexity and costs—reduced benefit from screening

1. Chronic obstructive pulmonary disease (COPD) and bronchiectasis.[19–21]
2. Cardiovascular disease (other than AAA).[19–21]

3. Atrial fibrillation and flutter.[19–21]
4. Other cardiac arrhythmia associated with perioperative complexity.[19 20]
5. Other malignant cancer, not including metastatic, upper gastrointestinal and lung cancer.[19 20]
6. Diabetes.[19–21]
7. Chronic kidney disease stage three or above including renal failure.[19–21]
8. Receiving dialysis.[19–21]

### D: Diagnoses that would reduce life span and associated with substantial reduction in quality of life—reduced absolute quantity and quality of life benefit from screening

1. Dementia.[21]
2. Hemiplegia or paraplegia.[21]
3. Hip fracture.[22]

### E: Other relevant factors to consider

1. History of smoking.
2. Current smoker.
3. Prior hospitalisations in the last 15 years.

The proportions of people who might have comorbidities similar to the participants of the Endovascular Aneurysm Repair (EVAR)-2 trial are estimated by counting the number of people who had any of the following: chronic kidney disease stage three or above including renal failure, cardiac arrythmia, COPD, respiratory failure, heart failure or cardiovascular disease.[23]

## Multimorbidity scores

The M3 index score is a validated multimorbidity index derived from using log hazard ratios for 1-year mortality modelled from 61 categories of chronic conditions based on hospital discharge diagnoses in the past 5 years.[20] The validation study (involving more than 1 million cases) has demonstrated that M3 index provides better prediction of 1-year mortality compared with Charlson or Elixhauser comorbidity scores based on c-statistics and integrated discriminative improvement.[20] M3 index has a positive log HR assigned for each of the 61 categories of chronic condition. A M3 index score of zero means the person does not have any of the chronic conditions diagnosed in a publicly funded hospital New Zealand in the past 5 years. To ensure comparability, the M3 index score for each individual was calculated using the identical chronic condition definition and methods as per original study with two exceptions.[20] First, any AAA diagnoses are excluded from the M3 index score calculations. Second, the M3 index scores calculated for this study did not include any diagnoses from AAA hospital events that ended 2 days prior to death as described by the exclusion rules of comorbidities analyses method above. This step is to ensure any complications or diagnosis arise from the final event resulting in death are not inadvertently misclassified as known comorbidities prior to the final event resulting in death.[20] This exclusion rule is expected to result in more conservative estimates of comorbidities, as some relevant diagnoses not related AAA rupture would also be excluded at the final event, for example, metastatic cancer. The more conservatively calculated M3 index scores of people who died from AAA were compared with the age specific scores of the general population in New Zealand.[20]

## Patient and public involvement

This study was carried out based on anonymous administrative data with no active patient or public involvement.

## Ethical approval

As all datasets were entirely based on anonymous administrative data with no active patient involvement, no formal ethical review was required as per New Zealand ethical guidelines (from New Zealand Health and Disability Ethics Committees).[24]

# RESULTS

There were 1094 deaths caused by AAA registered in the 5 years between 2010 and 2014 in New Zealand. The majority of the AAA deaths (77.5%, n=848) were people aged 75 or above (table 1). Males aged 65 or above accounted for 54% (n=596) of total AAA deaths. In 2014, overall AAA deaths accounted for only 0.7% of total deaths, and 1.0% of deaths among men aged 65 or above in New Zealand. This compares to England and Wales in 2015, where AAA accounted for 1.1% of total deaths as shown in tables 1 and 2 of online supplementary information.[25]

Out the 1094 AAA deaths, 31.3% had a known AAA diagnosis coded in a previous hospitalisation prior to the acute AAA event resulting in death (table 2). On average, the AAA diagnosis was known 3.7 years prior to death, with 58% of the AAA diagnosis known 2 years prior to death. Consistent with known AAA diagnosis, 32.9% (n=360) had a prior ultrasound, CT or MRI scan of the abdomen in hospital before the final acute AAA event. Out of the people (n=360) who had documented abdominal imaging, the first scans were carried out on average 4.2 years prior to death. Within the 15 years prior to death, 139 people had more than one scan (ie, had evidence of follow-up imaging studies). Many scans were relatively recent, with 43% of people having an imaging scan of the abdomen within the year prior to death and before the final acute AAA event. Moreover, 10.9% of the people dying from a AAA event had at least one previous abdominal aortic surgical intervention.

People who died from AAA often had competing comorbidities associated with a reduction in life span and/or quality of life. For example, 21.1% of people who died from AAA also had a heart failure hospitalisation prior to the acute event. Smoking related comorbidities were common: 52.9% had evidence of other cardiovascular disease other than AAA, 25.6% (n=280) had evidence of malignant cancer and 18.6% had COPD and/or bronchiectasis. Furthermore, 19.9% had dementia, hemiplegia, paraplegia and/or hip fracture. In fact, 77% of AAA

Table 1 Demographic characteristics of the deaths caused by AAA in New Zealand 2010–2014

| Characteristics | Number of AAA deaths | AAA deaths (%) |
|---|---|---|
| **Age bands (years)** | | |
| 35–44 | 1 | 0.1 |
| 45–54 | 2 | 0.2 |
| 55–64 | 43 | 3.9 |
| 65–74 | 200 | 18.3 |
| 75–84 | 432 | 39.5 |
| 85 and over | 416 | 38.0 |
| **Gender** | | |
| Females | 466 | 43 |
| Males | 628 | 57 |
| **Ethnicity** | | |
| Māori | 81 | 7.4 |
| Pacific | 22 | 2.0 |
| Asian | 19 | 1.7 |
| European/Other | 972 | 88.8 |
| **NZDep2013 Index of Deprivation** | | |
| Unknown | 24 | 2 |
| 1 (least deprived areas) | 56 | 5 |
| 2 | 87 | 8 |
| 3 | 81 | 7 |
| 4 | 94 | 9 |
| 5 | 96 | 9 |
| 6 | 131 | 12 |
| 7 | 155 | 14 |
| 8 | 123 | 11 |
| 9 | 120 | 11 |
| 10 (most deprived areas) | 127 | 12 |
| **Total** | 1094 | |

AAA, abdominal aortic aneurysm.

deaths had one or more of comorbidities as defined by this study (Groups 4–21 as shown in table 2).

Up to 64% (n=740) of all AAA deaths might have been potential candidates for the EVAR Trial 2 from a comorbidity point of view,[23] namely people who had renal dysfunction, cardiac arrythmia, COPD, respiratory failure, heart failure and underlying cardiovascular disease.

Of those people who had a prior AAA diagnosis (n=342), 31% had received abdominal aortic surgery in the past. Overall, 32.4% (n=354) either had a prior AAA diagnosis or received abdominal aortic surgery. Out of those people with prior AAA diagnosis and who had not had abdominal aortic surgery (n=235), 46%, 89% and 26% had at least one comorbidity within categories B, C and D respectively. Excluding those who had either prior AAA diagnosis, imaging or diagnoses strongly associated with poor prognosis (ie, those in categories A and B), this leaves 48.6% of the cohort (n=532). Out of the 532 deaths, 58% (n=309) had comorbidities (categories C and D) that would limit the benefits they would likely derive from a screening programme. In other words, 28% of overall AAA deaths (n=309) might be expected to accrue only a partial benefit from the screening programme because of competing comorbidities (did not have category A or B but have C or D). The subgroup analysis of men aged 65 or above, showed a very similar pattern of prior AAA diagnosis and comorbidities except for conditions that are known to have a major gender difference such as hip fracture. In summary, at most 20.4% of people dying from AAA in New Zealand might have the potential to accrue full benefit from a screening programme (people who did not have category A, B, C, or D). The overlap between categories is shown in online supplementary figure 1 of the online supplementary information.

People who died from AAA often had more than one prognosis-limiting disease category. More than 56% of AAA deaths had a prior hospitalisation with two or more diagnostic groups of comorbidities as defined by this study (within groups 3–21).

### M3 index score

Consistent with the descriptive findings (tables 2 and 3), 67% (n=738) of the AAA cohort had a M3 index score >0 (excluding AAA diagnosis from the M3 index scores) and had a much higher age specific M3 index score distribution compared with the general population in New Zealand (table 4).[20] Comparing the median M3 index scores for ages 65 or above, the hazard of 1-year mortality associated with the non-AAA related comorbidities for the AAA cohort was 1.5–2.6 times higher than compared with the age matched general population.

## DISCUSSION

AAA incidence and mortality has fallen substantially in many developed countries since the recruitments for the four randomised controlled trials of AAA screening from 1988 to 1999.[12 26–31] Particularly in countries where AAAs account for decreasing proportions of overall deaths, this study suggests a retrospective review of recent AAA deaths could be a helpful approach to quantify the potential impact of a screening programme for AAA in the contemporary setting. One of the primary objectives for screening for AAA is to reduce all-cause mortality at a population level. The all-cause mortality benefit from the four published randomised control trials of AAA screening has been a subject of intense debate predominately on the basis of statistical significance and modelling methods.[32–35] However, there is little discussion on whether the claimed 2% absolute all-cause mortality benefit demonstrated in trials at a time of higher incidence of AAA is still feasible in the context of falling AAA incidence and AAA mortality, considering AAA deaths only account for about 1% of

Table 2 Known medical history and comorbidities of people who died from AAA in New Zealand from 2010 to 2014 prior to the acute AAA event

| Description | Number | AAA deaths (%) | Number (men aged ≥65) | AAA deaths (men aged ≥65) (%) |
|---|---|---|---|---|
| 1. Known AAA diagnosis | 342 | 31.3 | 186 | 31.2 |
| 2. Previous abdominal aortic surgery | 119 | 10.9 | 69 | 11.6 |
| 3. Previous abdominal CT/MRI scan | 360 | 32.9 | 190 | 31.9 |
| A. Unlikely to benefit from a national AAA screening programme (groups 1–3) | 456 | 41.7 | 244 | 40.9 |
| 4. Palliative code | 46 | 4.2 | 24 | 4 |
| 5. Metastatic cancer | 24 | 2.2 | 12 | 2 |
| 6. Upper gastrointestinal cancers | 2 | 0.2 | 1 | 0.2 |
| 7. Lung cancer including mesothelioma | 15 | 1.4 | 11 | 1.8 |
| 8. Respiratory failure | 35 | 3.2 | 23 | 3.9 |
| 9. Heart failure (including cor-pulmonale) | 231 | 21.1 | 126 | 21.1 |
| 10. Cirrhosis, gastro-oesophageal varices | 8 | 0.7 | 4 | 0.7 |
| B. Diagnoses that are strongly associated with poor prognosis (groups 4–10) | 310 | 28.3 | 170 | 28.5 |
| 11. COPD and bronchiectasis | 204 | 18.6 | 116 | 19.5 |
| 12. Cardiovascular disease (excluding AAA) | 579 | 52.9 | 336 | 56.4 |
| 13. Atrial fibrillation and flutter | 255 | 23.3 | 153 | 25.7 |
| 14. Other cardiac arrhythmia | 93 | 8.5 | 54 | 9.1 |
| 15. Other malignant cancer, excluding metastatic, upper GI and lung cancer | 268 | 24.5 | 165 | 27.7 |
| 16. Diabetes | 109 | 10.0 | 65 | 10.9 |
| 17. Chronic kidney disease stage 3 or above | 109 | 10.0 | 65 | 10.9 |
| 18. Received dialysis | 11 | 1.0 | 7 | 1.2 |
| C. Diagnoses that reduce life span and/or increase operative complexity and cost (groups 11–18) | 806 | 73.7 | 451 | 75.7 |
| 19. Dementia | 67 | 6.1 | 31 | 5.2 |
| 20. Hemiplegia or paraplegia | 100 | 9.1 | 54 | 9.1 |
| 21. Hip fracture | 78 | 7.1 | 23 | 3.9 |
| D. Diagnoses that reduce life span and associated with substantial reduction in quality of life (groups 19–21) | 218 | 19.9 | 99 | 16.6 |
| **Have category A or B** | 562 | 51.4 | 301 | 50.5 |
| **Did not have Category A or B** | 532 | 48.6 | 295 | 49.5 |
| **Did not have Category A or B but have C or D** | 309 | 28 | 175 | 29.3 |
| **Have category B, C or D** | 842 | 77.0 | 467 | 78.4 |
| **Category A, B, C or D** | 871 | 79.6 | 476 | 79.9 |
| **Did not have Category A, B, C or D** | 223 | 20.4 | 120 | 20.1 |
| 22. History of smoking | 579 | 52.9 | 365 | 61.2 |
| 23. Current smoker | 335 | 30.6 | 186 | 31.2 |
| 24. Prior hospitalisations in the last 15 years | 997 | 91.1 | 536 | 89.9 |
| Total deaths | 1094 | | 596 | |

AAA, abdominal aortic aneurysm.

total deaths in many developed countries such as UK and USA.[1 34 35] The systematic reviewers for the US Preventive Services Taskforce indicated that all-cause mortality benefit from AAA screening is not convincing because AAA deaths are more likely to occur at older age and people with AAA often have other competing causes of death.[32] Furthermore,

Table 3 Number of people who died from AAA by the number of diagnostic groups of comorbidities

| Number of diagnostic groups of comorbidities | Number of people | AAA deaths (%) |
|---|---|---|
| 0 | 252 | 23.0 |
| 1 | 224 | 20.5 |
| 2 | 225 | 20.6 |
| 3 | 175 | 16.0 |
| 4 | 111 | 10.1 |
| 5 | 65 | 5.9 |
| 6 | 30 | 2.7 |
| 7 | 10 | 0.9 |
| 8 | 2 | 0.2 |
| **Total** | 1094 | |

AAA, abdominal aortic aneurysm.

a recent matched cohort study suggested that the absolute benefit from AAA screening for men in Sweden was only 7% of the absolute benefit demonstrated by the Multicentre Aneurysm Screening Study (MASS) randomised trial at two avoided AAA deaths from 10 000 invitees.[36] This present study has further consolidated the evidence base that screening for AAA is likely to have very limited impact (if any) on all-cause mortality because of the below reasons.

### Only small proportions of people dying from AAA in contemporary settings have the potential to receive the full benefit from a screening programme

In the absence of a formal AAA screening programme in New Zealand, this study demonstrated at most 20.4% of people dying from AAA in New Zealand might have the potential to derive full benefit from a screening programme. In addition, 28% of people might only receive a partial benefit from the screening programme because of competing comorbidities.

### Relatively large proportion of AAA were already identified prior to the acute event leading to AAA deaths in the absence of a formal screening programme

The diagnosis of AAA was relatively high (31.3%) prior to the acute AAA event resulting in death. The majority of prior AAA diagnoses were known more than 2 years prior to the AAA deaths. Consistent with the high level of prior diagnosis, 32.9% of people dying from AAA had at least one documented abdominal imaging prior to the acute AAA event resulting in death. Just under 11% had prior abdominal aortic intervention. The combination of these three groups would mean 41.7% of the AAA deaths would receive very minimal or no benefit from a one-off AAA screening. This study's findings are consistent with the claim made by a recent Sweden cohort study that a large proportion of AAA were already identified before rupture.[36] Their study concluded that the lack of statistical reduction in AAA mortality attributed to a AAA screening programme in Sweden may be associated with the high level of background diagnosis of AAA.[36] Indeed, the increase in opportunistic detection and diagnosis of AAA is likely to be associated with the rapid increase in the use of abdominal imaging since 1990.[37]

### People who die from AAA have a high prevalence of competing comorbidities

Despite excluding the AAA diagnosis and some of the diagnoses made in hospital events proximal to death as part of the M3 index score, people who died from AAA had a much higher level of complexity of comorbidities than the age matched general population in New Zealand

Table 4 Comparison between age specific M3 index scores (log HRs) between people who died from AAA and the general population in New Zealand

| | | M3 index scores of people who died from AAA prior to acute AAA event | | | | M3 index scores of general population | | |
|---|---|---|---|---|---|---|---|---|
| Age | Number of AAA deaths | Average | Median | 75th percentile | 90th percentile | Median | 75th percentile | 90th percentile |
| 35–39 | 1 | 0.33 | 0.33 | 0.33 | 0.33 | 0 | 0 | 0 |
| 40–44 | 0 | – | – | – | – | – | – | – |
| 45–49 | 0 | – | – | – | – | – | – | – |
| 50–54 | 2 | 0.19 | 0.19 | 0.28 | 0.34 | 0.0 | 0.0 | 0.2 |
| 55–59 | 10 | 1.04 | 0.82 | 1.44 | 2.83 | 0.0 | 0.0 | 0.3 |
| 60–64 | 33 | 0.55 | 0.00 | 0.64 | 1.85 | 0.0 | 0.0 | 0.4 |
| 65–69 | 78 | 0.78 | 0.41 | 0.99 | 2.00 | 0.0 | 0.0 | 0.6 |
| 70–74 | 122 | 0.59 | 0.18 | 0.82 | 1.80 | 0.0 | 0.2 | 0.8 |
| 75–79 | 179 | 0.66 | 0.33 | 1.18 | 1.78 | 0.0 | 0.4 | 1.1 |
| 80+ | 669 | 0.75 | 0.43 | 1.19 | 1.94 | 0.1 | 0.7 | 1.4 |

AAA, abdominal aortic aneurysm.

as demonstrated by the comparison of the M3 index scores. Since tobacco smoking is strongly associated with AAA,[31] it was not surprising to find that people who died from AAA also had many competing comorbidities which would limit the quality and quantity of life. Indeed, the subgroup with known AAA who had not received abdominal aortic interventions more often had more comorbidities that limit life span such as metastatic cancer and heart failure. This association is likely to be a challenge for predictive models to stratify the population for those best suited for screening, as people with higher risk of AAA may also be of higher risk of multimorbidity limiting their benefit from screening. The high prevalence of competing morbidities demonstrated in this study may also explain why it is challenging for newer surgical techniques such as EVAR to improve long term survival of people with AAA beyond 1 year, even though EVAR has significantly improved 30-day mortality compared with open repair.[38] Indeed, subgroup analyses from a recent individual level meta-analysis of randomised controlled trials comparing EVAR and open repair did not find early benefit from EVAR for people with moderate renal dysfunction or coronary heart disease.[38] Nevertheless, it would be important for policy makers to consider any new evidence that becomes available in regard to the longer term outcomes of new technological advances.

While many of the morbidities examined by this study are not absolute contraindications to abdominal aortic intervention, they often increase perioperative complexity and overall intervention costs as well as being associated with increased risk of postoperative complications and adverse events. In the context of inevitably treating people with AAA of whom the AAA would have otherwise never caused harm in their life time, it is important to consider the decision to undertake AAA intervention does not always translate to meaningful benefit to patients overall in terms of quality and/or quantity of life.

The EVAR-2 trial demonstrated that for people with AAA (≥5.5 cm) who were not eligible for open repair because of comorbidities, EVAR reduced aneurysm related mortality without increasing overall survival.[23] Up to 64% (n=740) of people who died from AAA might have been potential candidates for the EVAR Trial 2,[23] namely people who had renal dysfunction, cardiac arrythmia, COPD, respiratory failure, heart failure and underlying cardiovascular disease. Preventing a person from AAA rupture alone without significantly prolonging quantity and quality of life because of other morbidities may not be considered as desirable from a people centric point of view. This study highlights the type of common comorbidities that may be worth reviewing and optimising clinically before aortic intervention, as well as allowing a more informed consent about the likely benefits and potential harms related to the aortic intervention. For example, having an accurate assessment of a cancer prognosis or the functional status of people with dementia as appropriate; or optimising cardiovascular disease and heart failure management prior to proposed interventions.

### Opportunity to improve outcomes of people with AAA without implementing a AAA screening programme

Many of the wider potential benefits from a AAA screening programme could potentially be achieved without implementing a AAA screening programme. For example, better use of technology and quality assurance of vascular surgery can be carried out without the additional costs and harms related to a screening programme. The cohorts with known AAA or who have had prior AAA intervention are more likely to benefit from systematic quality improvement efforts towards surveillance and the management pathway. These quality improvement efforts can be implemented without a formal screening programme. The benefit of this approach is that it can limit the harms and overdiagnoses related to a screening programme which usually has a primary aim to detect AAA cases.[10]

For people with known AAA, the absolute risk of AAA rupture resulting in death is actually low. In people with AAA who would normally be entered into a surveillance programme (3.0–5.4 cm), rupture accounts for about 1%–1.6% of all deaths.[39] In the NHS AAA screening programme, the rupture risk of the 13 000 men under surveillance is reported to be <0.5%0.[4] Even for people with 5.5–6.9 cm AAA which is surgically indicated for AAA repair, the risk of rupture is estimated to be less than 5% per year.[40] In the context of competing comorbidities, about half of the large AAA who did not have operations died from other causes.[40] Therefore, there is time to optimise management of comorbidities before elective intervention, or conservative treatment may be appropriate in some cases.

In the contemporary setting, other potential health and cardiovascular benefits from AAA screening programme such as improving CVD management, and support for smoking cessation, are less likely to be realised in countries such as New Zealand where coverage of the eligible population for cardiovascular risk assessment is at 90%.[41] Indeed, a weighted meta-regression study of 10 articles demonstrated that out of a group of people with AAA (3.0–5.4 cm), there were eight times more deaths from other cardiovascular causes than from AAA rupture, emphasising the importance of CVD management in people with AAA.[39] If one is concerned about CVD risk, then designing interventions to more directly improve systematic CVD risk management in primary care could be suggested without the additional cost and potential harms related to a AAA screening programme.

### Time to revise the inputs and assumptions of published cost effectiveness studies that have informed policy

One has to be cautious in accepting the frequently quoted claims that AAA screening remains cost effective as long as AAA prevalence is above 0.35% based on one-way sensitivity analysis.[4 16] Many assumptions of such cost effectiveness models deserve more scrutiny and re-calibration with contemporary data and latest evidence is urgently required to better inform policy. For example, the cost

effectiveness model for the NHS screening programme is based on 10-year results from the MASS trial.[16] The absolute benefit from the screening programme is expected to be much less than the results from the MASS trial in the context of rapidly falling AAA mortality with AAA accounting for proportionally less of total deaths. Indeed, contemporary real world impact observed may be substantially less than demonstrated by historical randomised controlled trials.[36] The lack of statistically significant AAA mortality benefit in the Western Australia Trial may be at least partly related to the high background abdominal screening.[4 29] The increase of prior diagnosis and background abdominal scans in the contemporary setting would also be expected to reduce the relative benefit of the screening programme. This study reports 32.4% of the AAA deaths (n=354) either had a prior AAA diagnosis or received abdominal aortic surgery before the acute AAA event leading to death and 41.7% had prior CT/MRI scan of the abdomen, or a AAA diagnosis or aortic procedure. This compares to a recent cost effectiveness model output of only 19% of AAA rupture incidentally detected prior to rupture.[42]

The UK cost effectiveness model would not be realistic in New Zealand setting as it assumed AAA accounted for 3.6% and 2.3% of total deaths in the controlled and invited group claiming an absolute benefit of 0.9% of overall mortality from screening.[16]

Consistent with published literature,[32] this study clearly demonstrates people who died from AAA had substantially more complex comorbidities associated with 1-year mortality compared with the general population as demonstrated by M3 index scores. Indeed, the median survival of trial participants from EVAR-1, Dream, OVER and ACE at an average age of 71.7 years was around 8–9 years.[38] This was lower than the life expectancy of the general UK population at aged 72 which was 13.3 years for males and 15.3 years for females.[43] However, many of the cost effectiveness models assume that people with AAA have same age specific mortality and quality of life as the age matched population.[16 17 42] This unrealistic assumption is likely to result in substantially over estimating the benefits in life years and Quality Adjusted Life Years.

Finally, all the relevant costs of the screening pathway are often not adequately captured by cost effectiveness modelling. For example, the perioperative and long-term complications from AAA repairs are not insignificant. Aneurysm-related intervention or intervention for complications at 8 years were estimated to be 25% for endovascular repair and 20.6% for open repair.[44] While the latest cost effectiveness model for AAA screening has made some technical improvements in some parts of the modelling, complications rates are informed by the EVAR-1 trial only.[42] The prognosis, complication rates and costs for people with comorbidities such as candidates of EVAR-2 trial are not adequately captured resting in a more optimistic result.[23] Moreover, cost effective models for AAA screening do not have documented methods to account for the wider range of practical costs related to implementing the AAA screening pathway in the real world such as proportions of patients who did not attend screening or surgical appointments.[16 17]

### Strengths and limitations of the study

This study is based on ICD coding of administrative data which is widely available internationally and is able to cover the whole country, limiting selection biases. The methods could be replicated in other countries to inform continual quality improvement of existing screening programme as well as investment and disinvestment decisions. Indeed, the findings of this study could be used to validate many of the inputs, outputs and assumptions of cost effectiveness models of AAA screening that inform policy and quality improvement efforts.[16 17 42] The choice of prognostic limiting diagnoses were informed by the review of the medical literature,[19] or based on disease categories that had empirical data to demonstrate the association of high short-term mortality risk,[20 22] and/or had been associated with high morbidity burden as defined by the disability weights from the Global Burden of Disease Study.[21]

This study has a number of limitations. The percentage of people who had prior abdominal aorta imaging is likely to be significantly underestimated because abdominal ultrasound scans are not routinely coded in the hospitalisation datasets, and outpatient, community or privately funded ultrasound, CT and MRI imaging of the abdominal aorta were not counted. The diagnoses examined were based on cancer registry or hospitalisation codes, but comorbidities diagnosed in the community or comorbidities yet to be diagnosed were not available to be examined. Furthermore, the definition of the disease groupings was designed to optimise specificity and clinical relevance to the AAA intervention pathway, and severe forms of the disease are chosen. For example, only a more severe forms of chronic kidney disease are examined. As a consequence, some disease definitions used by this study are different from the M3 index, although actual M3 index scores were also calculated using the official M3 index disease definition. These limitations mean this study will still tend to underestimate the impact of the factors examined on the estimation of benefits and harms of AAA screening for cost effectiveness modelling. The under capture of opportunistic imaging and comorbidities of this study means it would provide a relatively optimistic view of true screening benefits. However, we believe applying these assumptions will be more realistic for the contemporary situation than the assumptions being applied in the current cost effectiveness models.[16 17 42] It is possible that the number of AAA deaths might be under reported. However, the number of under reporting is likely to be very small if any because of several reasons. Imaging studies are widely accessible in an acute or elective setting, and publicly funded in New Zealand. Rupture of AAA is highly symptomatic, which may prompt the patient to seek care, or provide a co-lateral history that makes misclassification as a cause of death

less likely. All sudden, unexpected or unexplained deaths are reported to the coroners in New Zealand.[45] Additional investigations and autopsies are undertaken for cases where cause of death was uncertain and/or would be of public interest. Even if there are cases where the AAA rupture are misclassified, the deceased would have been likely to have significant comorbidities that would have significantly limited any potential benefit accrued from a screening programme. It is also possible the people with known AAA who died suddenly from other causes may be misclassified inappropriately as AAA. New Zealand Ministry of Health has reviewed mortality coding related to ruptured AAA and provided reassurance that there is no documented AAA death misclassified by coding (C Fowler, AAA deaths, Ministry of Health, personal communication, 2017).

Since most people with AAA died from competing comorbidities,[39] a retrospective review of AAA deaths is less likely to find severe forms of comorbidities that are strongly life span limiting compared with a prospective study of people with known AAA at a time of death.

## CONCLUSION

Falling AAA mortality, high level of background abdominal imaging and competing comorbidities are expected to substantially reduce the cost effectiveness of a screening programme for AAA. The data in our study suggests many published cost effectiveness modelling papers may over-estimate the potential benefit from formal screening. Reasons include falling AAA mortality, high level of comorbidities, future life expectancy post AAA repair and the impact of incidental detection not being sufficiently taken into account. The use of real-world data from the methods and results are likely to be helpful in calibrating those models to better inform prioritisation conversations with a variety of stakeholders, including community and patient groups, about a range of competing funding priorities.

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