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A geospatial analysis of geographical and population disparities in timely access to prehospital and advanced level emergency care in New Zealand

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ABSTRACT

OBJECTIVE: Rapid access to advanced emergency medical and trauma care has been shown to significantly reduce mortality and disability. This study aims to systematically examine geographical proximity and access to prehospital care provided by Emergency Medical Services (EMS) and advanced-level hospital care, for the smallest geographical units used in New Zealand and explores national disparities in geographical access to these services.

DESIGN: Observations study involving geospatial analysis of population access to EMS and advanced-level hospital care.

SETTING: Population access to advanced-level hospital care via road and air EMS across New Zealand.

PARTICIPANTS: New Zealand population usually resident within geographical Census meshblocks.

PRIMARY AND SECONDARY OUTCOME MEASURES: The proportion of the resident population with calculated EMS access to advanced-level hospital care within 60 minutes was examined by age, sex, ethnicity, level of deprivation, and population density to identify disparities in geographical access.

RESULTS: An estimated 16% of the New Zealand population does not have timely EMS access to advanced-level hospital care. The 700,000 New Zealanders without timely access lived mostly in areas of low-moderate population density. Indigenous Māori, New Zealand European and older New Zealanders were less likely to have timely access.

CONCLUSIONS: These findings suggest that in New Zealand, geographically marginalised groups which tend to be rural and remote communities with disproportionately more indigenous Māori and older adults have poorer EMS access to advanced-level hospitals. Addressing these inequities in rapid access to medical care may lead to improvements in survival that have been documented for people who experience medical or surgical emergencies.

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KEY WORDS: Emergency Medical Services; Geospatial; GIS; Hospital; Health Services Access; Time-to-treatment

Article Summary

Strengths and limitations of this study

This study is the first step in assessing access to emergency medical services (EMS) in New Zealand, a long, narrow and geographically challenging island nation in the South Pacific with a small, geographically dispersed population.

This study expands on previous international assessments of timely access to emergency hospital-level care by mapping exact locations of EMS response.

The choice of geospatial software and consciously conservative assumptions chosen made are likely to underestimate the impact the theoretical access estimates presented.

The EMS scenario theoretically modelled in our analysis fits a "scoop & run" strategy to prehospital care, and does not consider other prehospital strategies, such as a differentiated strategy, or rapid delivery of specialist medical expertise to the patient.

INTRODUCTION

Globally, millions of people with life-threatening injuries or health events require rapid and timely access to advanced healthcare services to prevent needless mortality and morbidity. The public health burden of time-critical medical emergencies can be further exacerbated in countries with challenging terrain, long travel distances, and dispersed populations, despite relative economic standing and available resources. New Zealand is one country where these natural and population features are a daily challenge to the timely and equitable delivery of prehospital emergency care.

Death and disability due to acute medical emergencies can be significantly reduced by the timely provision of prehospital emergency healthcare, thereby presenting many opportunities for tertiary prevention. Optimal models of trauma care delivery, focusing on a continuum of timely emergency medical services (EMS) to efficient in-hospital care, start with the rapid provision of prehospital EMS, provide the best chance for survival and rehabilitation following injury.[1-3] A time sensitive approach has also been proven to benefit patients requiring EMS following cardiac, stroke and vascular events.[4 5]

EMS are a vital entry point into the continuum of acute emergency health care, as their primary role is to rapidly meet the emergency prehospital care needs of patients following time-critical injury or health events. In terms of receiving hospital-level treatment, the first hour, commonly referred to as the 'golden hour', is generally considered to be the most critical in terms of receiving definitive treatment for cases with time-critical injuries or health conditions.[2] Although not supported by a strong evidence-base, access to EMS and advanced-level hospital care is often judged against this threshold.[6 7] Disparities in timely access to advanced-level hospitals have been documented in numerous countries, identifying higher risk of delayed access for communities and vulnerable groups.[6 8-11]

New Zealand's mountainous terrain, long travel distances, and relatively small and geographically dispersed population of 4.2 million can severely hinder physical/transport access to advanced hospital-level care impacting timely and equitable delivery of prehospital EMS. New Zealand's population density is relatively low at 15 people per square kilometre, considerably less than countries with similar land area such as the United Kingdom with 243 people per square kilometre. Despite having low overall population density, New Zealand is highly urbanised, with 86% of the population living in urban areas.[12] Case reviews in New

Zealand suggest there are opportunities to improve prehospital EMS and reduce the number of prehospital deaths.[13 14]

This study systematically examines geographical proximity and access to prehospital care provided by EMS and advanced-level hospital care, for the smallest geographical units used in New Zealand, in order to identify opportunities to improve survivability and reduce disability following time-critical medical emergencies, and explores national disparities in geographical access to these services.

METHODS

Advanced level hospital care in New Zealand

There are three levels of classification for New Zealand hospitals, relating to their capability to provide the appropriate services for seriously injured or ill patients (Table 1). New Zealand has a unique system where by trauma response, treatment, and rehabilitation are funded by the universal, no-fault, publicly funded Accident Compensation Corporation (ACC). In contrast, medical response, treatment and rehabilitation is publicly funded by each individual District Health Board with some part-charges for ambulance services.

Data sources

For this study we used Census 2013 (most recent publically available data) meshblock boundary and characteristics information available from Statistics New Zealand.[15] Meshblocks are the smallest geographical unit available. In the 2013 census there were 45,989 meshblocks ranging in size from part of a city block containing approximately 110 people to a large area of rural land containing approximately 60 people. In addition to the boundary shapefiles, we obtained sociodemographic, deprivation and urbanity characteristics of the population usually residing within each meshblock.[15]

The physical addresses of advanced-level (Level 1 and 2) hospitals were converted to geographical longitude-latitude coordinates. The locations of road ambulance stations as at 2014/15 were obtained from the two providers of these services in New Zealand, St. John Ambulance (New Zealand's major provider serving 98% of the population) and Wellington Free Ambulance. Air EMS services were restricted to helicopter based services in use in 2016 and their longitude-latitude coordinates were derived from multiple sources, including the Civil Aviation Authority, the Hawkes Bay Rescue Helicopter Trust, and Google Maps. Road

network data was obtained from www.geofabrik.de, an online open street map and spatial data provider.

Geospatial access calculations

Timely access was defined as the proportion of the population or land area from which an injured person was theoretically able to reach an advanced-level hospital within a given time (30, 45, 60, 90 and 120 minutes) via air and road EMS. Access was calculated using established geospatial methods previously described elsewhere.[6 16] The time required for the nearest air or road EMS to reach the geometric centroid of a meshblock, stabilise a patient, and then travel to the nearest advanced-level hospital was calculated for every meshblock.

Road network travel times included the following assumption obtained from St Johns: immediate response and average road ambulance time at scene 14 minutes and 49 seconds. All road calculations assumed ambulances drove at legal road speed, did not stop at intersections, driving conditions were ideal (i.e. no congestion), and ambulances drove the shortest route. Road ambulance drive times were calculated using the Open Source Routing Machine (OSRM available at www.project-osrm.org).

Air EMS travel times assumed helicopters flew in straight lines at an operational speed of 182 km/hour, response time (preparation for lift-off) of 8 minutes, on scene time of 27 minutes and 28 seconds, plus 32 seconds to find a safe pick-up landing site.[17] Air EMS flight times were calculated using custom written Python code running inside QGIS software.

Sociodemographic variables

Demographic data on age, sex and ethnicity was obtained by summing the subtotal of each characteristic across all meshblocks, thus estimating the population of New Zealand at the time of the 2013 Census. Age was grouped into five categories: 0-14, 15-29, 30-44, 45-64 and ≥65 years. The five categories of ethnicity used were: Māori (Indigenous population), Pacific, Asian, New Zealand European, and MELAA (Middle Eastern, Latin American, African) and Other. Census ethnicity data is not prioritised, with individuals able to record multiple ethnicities, therefore all ethnicities reported are counted resulting in totals greater than 100%.

Deprivation was derived using the 2013 New Zealand Deprivation Index (NZDep), which aggregates and ranks communication, income, employment, family support, qualifications, home ownership, living space and transport within each meshblock area.(26) NZDep deciles were categorised into quintiles, with '1-2' representing the least deprived 20% and '9-10' the most deprived 20% of meshblocks in New Zealand. Population density within each meshblock area was calculated using number of usually resident people divided by meshblock area, grouped into three categories: high (20 to <200,000), medium (2 to <20) and low (0 to <2 persons per kilometre).

Statistical analyses

Our unit of analysis was the 2013 Census meshblock. The count of usually resident populations within each Census 2013 meshblock was summed across the country to obtain national denominators. The sociodemographic, deprivation and urbanity characteristics of the population unable to access advanced-level care within key times are described using row percentages.

A map of New Zealand was created to provide a visual representation of the areas within New Zealand that cannot access advanced-level hospital care via air and road EMS within 60 minutes.

Ethical Approval

Ethical approval for the broader programme of research (24), of which this specific study is a part of, was obtained from the University of Auckland Human Participants Ethics Committee (ref 016179), National Coronial Information System (ref NZ007) and University of Otago Health and Disability Ethics Committee (ref OTA/90/02/008/AM05).

RESULTS

Access to advanced-level hospital care by air or road EMS takes over 60 minutes for the majority (84%) of New Zealand's land area. While less than 16% of our land area allows emergency access within 60 minutes, a substantial majority (83%) of New Zealanders live within those areas which do have timely access to advanced hospital level care within 60 minutes (Table 2). Close to one quarter (24%) of New Zealanders are estimated to have access to advanced-level hospital care within 30 minutes and two thirds (66%) within 45 minutes, 13% of the population are estimated to take up to 30 minutes longer than the 'golden hour' (i.e. within 60-90 minutes), and 4% are estimated to take greater than 90 minutes to access to advanced level hospital care.

Population differences in timely access were observed by ethnicity and population density. Persons identifying with Pacific, Asian or MELAA ethnic groups have the best theoretical access to hospital level care, with only 1-2% residing in meshblocks greater than 90 minutes away from Level 1 or 2 hospital care. In contrast, those of Māori or New Zealand European ethnicity had the poorest level of access with 4% and 3% respectively living in meshblocks greater than 90 minutes away from advanced-level hospital care. With respect to population density, access was poorest for people usually residing in lower density areas meshblocks, with 27% of people usually resident in low density areas versus 2% of people usually resident in high density areas being greater than 90 minutes away from either Level 1 or 2 hospital care.

Timely geographical access to our most advanced Level 1 hospital care is poorest for those aged 65 years or greater, those of Maori, New Zealand European, and Other ethnic groups, residents with high levels of deprivation, and those usually residing in the central North Island and lower South Island (Table 3). The addition of regional Level 2 hospital care expands the catchment from 60% of the population residing in meshblocks with access to advanced-level hospital care (Level 1 and 2) within 60 minutes to 84% (Table 3). In terms of land area access this equates to 5% of New Zealand's total land area with timely access to Level 1 hospital care within 60 minutes, which increases to 16% with the addition of Level 2 hospital care (results not in table).

Sub-population differences exist in timely access observed by age, ethnicity, level of deprivation and population density (Table 3). The oldest New Zealanders (65+ year olds) have the least access to Level 1 and combined Level 1 and 2 hospital care. No differences were observed by sex. Less than half of the Māori population reside in geographical areas with timely theoretical access to Level 1 hospital care, increasing to 79% with the inclusion of Level 2 hospital care, but still lower than other ethnic groups examined. Geographical areas with timely theoretical access to hospital care have a high proportion of resident Asian, Pacific and MELAA ethnic groups. The proportion of the population with timely access to advanced-level hospital care declines with increasing levels of deprivation, the exception to this is the most deprived group (NZ Dep 9-10) for whom access increased slightly from the previous level of NZ Dep 7-8, reflecting many of highly deprived areas in New Zealand are located in main urban areas close to hospitals. Those residing in meshblock areas with the least deprivation have the greatest degree of timely access. Regions with low to medium population density have the poorest access to prehospital care, with a paltry 3% of those usually residing in areas of low population density having access to a Level 1 hospital, expanding to 15% with the inclusion of Level 2 care.

Figure 1 provides a visual representation of the catchment of air and road EMS given the placement of advanced-level hospitals and EMS bases. Comparing a) and c) provides some illustration of why timely access to usually resident population is high, but land area access is low. Timely access is clustered around the main highly populated areas with a population density in the range 20 to <200,000 people per kilometre. Air EMS services improve the level of timely access to advanced hospital level care above and beyond road EMS services in all areas except two in the lower South Island. However, much of the coverage is "doubled-up" as the combined road/air catchment closely follows the road only catchment. Many areas of moderate population density are not adequately covered by EMS, and the most isolated pockets of non-coverage are in areas with low population density.

DISCUSSION

This research examined the proportion of the usually resident population with theoretical timely access to advanced-level hospital care by air and road EMS in New Zealand and identified disparities in access to these prehospital services. Not surprisingly, timely access is clustered around areas of high population density based on where New Zealand's population usually resides. Applying the concept of the 'golden hour', we estimate 16% of the New Zealand population does not have timely theoretical access to advanced-level hospital care. This equates to around 700,000 New Zealanders without timely access; particular disparities in theoretical timely access were observed for Māori, European New Zealanders, older New Zealanders and those residing in the lower South Island. Regionally based Level 2 hospital services are vital for rural communities to have timely access to care, particularly the Central North Island region where we estimate there is no timely access to the most advanced Level 1 hospital care within 60 minutes.

Previous international studies examining timely theoretical access to care following time-critical acute medical and trauma events have mainly focused on access to trauma services. Prehospital access to advanced trauma care in New Zealand is similar to that observed in the United States and Canada.[6 8 9] Timely access to advanced trauma care via road or air EMS was available to 88% of all United States residents, while 77% of Canadian residents have access via road ambulances.[8 9] Access to critical care services in Scotland is more comprehensive than New Zealand with 94% of the Scottish population within a 45 minute ambulance drive to definitive hospital-level care covering 47% of the Scottish landmass.[18] Unsurprisingly, the catchment of EMS and advanced-level hospital care aligns closely to population density in New Zealand, as also demonstrated in the United States, Canada and Scotland. Advanced-level hospital services are located to serve a large population base making the most efficient use of the resource and maintaining high levels of medical skill and management. This focus on areas of high population density, however, means that areas of disparities are generated on the basis of population density and dispersion. Areas of low to medium population density that have poorer EMS coverage typically have disproportionately greater indigenous Māori and ageing New Zealand European populations, high risk economic activity (such as farming and forestry), and remote areas of recreational and tourist activity.

Our study found significant socio-demographic disparities in timely theoretical access for indigenous Māori, New Zealand Europeans, older New Zealanders and those residing in the

southern part of the South Island, reflecting the geographical spread of New Zealand's population. While most Māori live in urban areas, Māori make up a higher proportion of the population residing in highly rural and remote areas, by contrast almost all Pacific and the majority of Asian people in New Zealand live in urban areas.[19] Older New Zealanders, who are typically New Zealand European, contribute to a high proportion of those who live in rural areas with low to moderate urban influence, explaining the longer theoretical access times observed for this group. Regions with low to moderate population density stood out as being significantly underserved when compared with areas of high population density. Similar disparities in access to advanced-level hospital care have been reported internationally for those residing in rural areas or very remote areas, and for ethnic minorities.[6 8-10 18] Our study provides further evidence of disparities in timely theoretical access to healthcare for Māori and for rural communities, and the unequal distribution of healthcare resources across New Zealand providing a further pathway for health disparities for Māori and rural populations: difficulties in achieved access to healthcare for these sub-groups are already well documented.[20 21] Our results add further support for EMS and advanced-level hospital services to be optimally configured to address both the geospatial and socio-demographic challenges of timely access relative to population density in New Zealand.

The optimal placement or enhancement of EMS retrieval and transfer services and advanced healthcare facilities in New Zealand should be examined further. One of the guiding principles for New Zealand's health system is that all New Zealanders have "timely and equitable access" to a "comprehensive range of health and disability services".[22] Our study found concerning geospatial disparities in timely geographical access for communities with low to moderate population density which tend to be rural and remote communities with disproportionately more Māori and older New Zealand Europeans. Furthermore areas with few permanent residents are popular destinations for international and residential tourists traveling to, and engaging in, outdoor tourist pursuits in remote back country and alpine areas. We have identified the need for the combined reach of EMS services and advanced-level hospital care to consider coverage of socio-demographic and geospatial aspects beyond just high density residential population bases.

Understanding the geospatial distribution of EMS services and timely access into advanced-level hospital care is the first step in identifying opportunities for improved care and planning of future services and health policy in the prehospital setting of an advanced trauma and

medical system. It is unknown if this current level of under-service results in higher rates of mortality across New Zealand, and future analyses from this research team will examine this question further with regard to injury.[16] Geographical areas with limited prehospital air and road EMS may be adequately served by other groups of appropriated trained first responders, such as General Practitioners, Police and Fire Services, where they sit outside of existing EMS catchment areas. Future research should examine the location of other first responders and the expansion of coverage of EMS these groups potentially provide. Other approaches to extending access to EMS and advanced-level hospital care include increasing, upgrading or integrating the roles of regional Level 3 hospitals in the provision of emergency care; expanding helicopter provision, repositioning existing road or air EMS depots, or providing novel methods such as delivery of advanced care to critically injured patients or telemedicine interventions.[6 9]

This study has a number of limitations. The choice of geospatial software and assumptions made are likely to impact the theoretical access estimates presented; we have consciously chosen conservative assumptions and settings meaning the proportion without timely access is likely to be underestimated. This analysis also assumes simultaneous dispatch by road and air EMS services, however the operational reality is that air response can take longer when emergency first responders are required to assess severity of an acute event prior to helicopter dispatch. The benefits of the extended air ambulance coverage identified in our analysis would therefore only be achieved if air ambulance services were dispatched without delay. Early/ simultaneous activation models have shown clear benefits for prevention of needless deaths.[23 24] A further limitation is that the EMS scenario theoretically modelled in our analysis fits a “scoop & run” strategy to prehospital care, and does not consider other prehospital strategies, such as a differentiated strategy, or rapid delivery of specialist medical expertise to the patient.[25] Recent empirical evidence suggests that a prehospital strategy should differentiate by injury type, with the worst case scenario injuries involving penetrating haemodynamically unstable injury or neurological trauma needing to reach advanced care as quickly as possible to have the best chance of survival.[26]

Our study expands on previous geospatial examinations of access in New Zealand [27] and internationally [6 9 18] with the use of actual location of road and air based EMS services, with comparison to usually resident population densities, to assess the actual level of EMS coverage and response providing valuable geospatial analyses to inform future planning and expansion of prehospital EMS in New Zealand. As New Zealand is an island nation with a universal nationally funded health care system we are able to consider the closest hospital care without being restricted by State, Provincial or National funding boundaries, unlike some international studies.

Conclusion

Timely access to advanced-level hospital care is important to increase survival from time-critical acute injury and medical events. Our study highlights the need for planning of EMS coverage in areas of moderate to low population density in New Zealand, especially for areas of moderate to low population density, in order to address inequities with regard to timely access to advanced-level hospital care. The geographical configuration of EMS and healthcare systems is important for optimising accessibility to services and promoting the efficient use of scarce resources in a geographically challenging island nation. Future analyses will examine if disparities in timely access to advanced-level hospital care translates into higher rates of mortality due to time critical injuries in New Zealand and identify areas requiring improved access to EMS and advanced-level hospital care relative to the burden of prehospital fatal injury.[16]

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Author contributors

R.L. contributed to the study design, conducted the literature review, provided oversight of the spatial analysis and was primarily responsible for the article preparation. B.dG. was primarily responsible for acquiring data and the spatial analysis, as well as contributing to the interpretation of data and preparation of the paper. G.D. contributed to the study design, provided advice on the spatial analysis methods, overseeing the spatial analysis and contributed to the interpretation of data and preparation of the paper. B.K. contributed to the study design, provided oversight of the project, interpretation of results and article preparation. C.B. contributed to the study design, provided advice on the spatial analysis methods and contributed to the direction of the analysis and interpretation of data and preparation of the paper. P.R., A.S., I.C., & B.D. contributed to the study design and to the interpretation of data and preparation of the paper.

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Competing Interests

The authors have no competing interests to declare.

Patient consent

Patient level data was not utilised in this study.

Ethics approval

Ethical approval for the broader programme of research (24), of which this specific study is a part of, was obtained from the University of Auckland Human Participants Ethics Committee (ref 016179), National Coronial Information System (ref NZ007) and University of Otago Health and Disability Ethics Committee (ref OTA/90/02/008/AM05).

Data sharing statement

Data are available from the corresponding author and access to these data will be considered on a case-by-case basis.

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Table 1. Categories of advanced levels of hospital care in New Zealand

Level of hospital care	Services provided	Hospital locations
Level 1	Advanced trauma and medical services based around comprehensive intensive care units with specialist staff.	Main population areas
Level 2	Capable of initial resuscitation and management. If specific intensive care not available then major trauma and severely ill patients transferred to Level 1 advanced care	Regional & rural provincial areas
Level 3	Run by non-specialist staff, capable of initial resuscitation. Major trauma and severely ill patients transferred to Level 1 advanced care.	Small rural areas

Table 2. Overall population and sub-population access to advanced-level hospital care by road and helicopter EMS within specified time periods.

Socio-demographic characteristics	**Have access to Level 1 or 2 hospital care within each specified period Minutes (row %)**				
	Within 30	**30-45**	**45-60**	**60-90**	**Greater than 90**
Total Population	24	42	17	13	4
Age (years)					
0-14	22	44	19	13	4
15-29	32	41	15	10	3
30-44	25	44	17	11	4
45-64	22	42	19	14	4
≥65	22	40	18	17	4
Sex					
Male	24	42	17	13	4
Female	24	42	18	13	4
Ethnicity					
New Zealand European	22	40	19	15	3
Māori	23	36	19	17	4
Pacific	26	54	15	5	1
Asian	32	20	6	3	1
MELAA	31	52	9	5	2
Other	24	42	17	13	3
Not Stated	24	42	17	13	3
NZ Deprivation Index					
1-2 (least deprived)	14	54	21	7	4
3-4	19	45	19	14	4
5-6	24	39	17	17	4
7-8	32	35	15	16	4
9-10 (most deprived)	32	36	15	13	4
Population Density					
(persons per km^2)	26	46	14	58	2
High (20-<200,000)	0.3	8	37	45	10
Medium (2-<20)	0.015	1	14	57	27
Low (0-<2)					

Table 3. Usually resident population access to different levels of advanced-level hospital care by road and helicopter EMS within specified time periods

Demographic characteristics	**Level 1 hospital access**	**Level 1 and 2 hospital access**
	Within 60 minutes Row %	**Within 60 minutes Row %**
TOTAL	59.8	84.6
Age (years)		
0-14	59.8	84.3
15-29	67.3	88.0
30-44	64.3	86.1
45-64	58.0	82.6
65+	50.7	79.4
Sex		
Male	59.7	83.4
Female	59.9	83.9
Ethnicity		
New Zealand European	55.3	81.5
Māori	45.6	78.7
Pacific	84.4	94.7
Asian	87.4	96.1
MELAA	82.9	93.0
Other	52.7	80.8
Not stated	59.9	83.7
NZ Deprivation Index		
1-2 (least deprived)	73.4	90.0
3-4	62.0	83.0
5-6	54.9	79.9
7-8	53.9	80.5
9-10 (most deprived)	55.1	83.6
Population Density (persons per km^2)		
High (20-<200,000)	64.3	88.0
Medium (2-<20)	17.1	45.3
Low (0-<2)	2.8	15.2

Figure 1 legend

Figure 1. Access to advanced-level hospital care in New Zealand within 60 minutes. a: Population density. b: Road EMS coverage. c: Road or air EMS coverage.

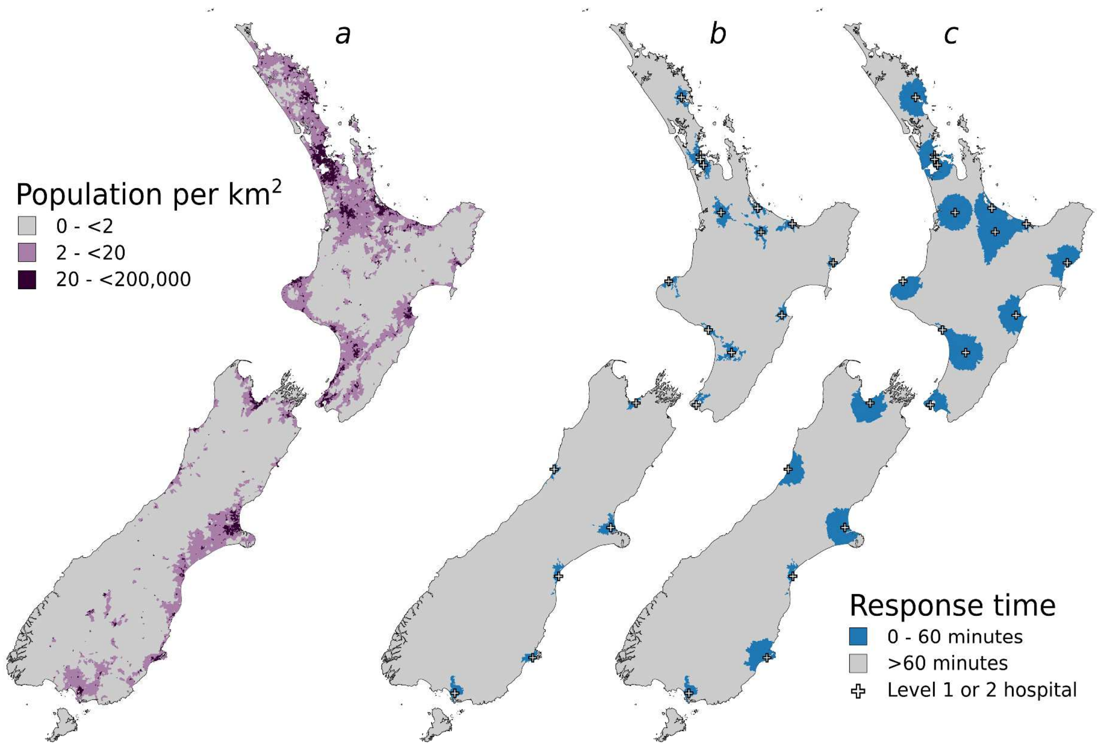

Figure 1. Access to advanced-level hospital care in New Zealand within 60 minutes. a: Population density. b: Road EMS coverage. c: Road or air EMS coverage.

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Geographical and population disparities in timely access to prehospital and advanced level emergency care in New Zealand: a cross-sectional study

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Short: Disparities in access to prehospital trauma and medical care in NZ

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ABSTRACT

OBJECTIVE: Rapid access to advanced emergency medical and trauma care has been shown to significantly reduce mortality and disability. This study aims to systematically examine geographical access to prehospital care provided by Emergency Medical Services (EMS) and advanced-level hospital care, for the smallest geographical units used in New Zealand and explores national disparities in geographical access to these services.

DESIGN: Observational study involving geospatial analysis of theoretical population access to EMS and advanced-level hospital care.

SETTING: Population access to advanced-level hospital care via road and air EMS across New Zealand.

PARTICIPANTS: New Zealand population usually resident within geographical Census meshblocks.

PRIMARY AND SECONDARY OUTCOME MEASURES: The proportion of the resident population with calculated EMS access to advanced-level hospital care within 60 minutes was examined by age, sex, ethnicity, level of deprivation, and population density to identify disparities in geographical access.

RESULTS: An estimated 16% of the New Zealand population does not have timely EMS access to advanced-level hospital care via road or air. The 700,000 New Zealanders without timely access lived mostly in areas of low-moderate population density. Indigenous Māori, New Zealand European and older New Zealanders were less likely to have timely access.

CONCLUSIONS: These findings suggest that in New Zealand, geographically marginalised groups which tend to be rural and remote communities with disproportionately more indigenous Māori and older adults have poorer EMS access to advanced-level hospitals. Addressing these inequities in rapid access to medical care may lead to improvements in survival that have been documented for people who experience medical or surgical emergencies.

FUNDING: Health Research Council of New Zealand (HRC 15/186)

KEY WORDS: Emergency Medical Services; Geospatial; GIS; Hospital; Health Services Access; Time-to-treatment

Article Summary

Strengths and limitations of this study

This study is the first step in assessing access to emergency medical services (EMS) in New Zealand, a long, narrow and geographically challenging island nation in the South Pacific with a small, geographically dispersed population.

This study expands on previous international assessments of timely access to emergency hospital-level care by mapping exact locations of EMS response.

The choice of geospatial software and consciously conservative assumptions made are likely to underestimate the impact the theoretical access estimates presented.

The EMS scenario theoretically modelled in our analysis fits a "scoop & run" strategy to prehospital care, and does not consider other prehospital strategies, such as a differentiated strategy, or rapid delivery of specialist medical expertise to the patient.

INTRODUCTION

Globally, millions of people with life-threatening injuries or health events require timely access to advanced healthcare services, including prehospital emergency services, to prevent needless mortality and morbidity.[1] The public health burden of time-critical medical emergencies can be further exacerbated in countries with challenging terrain, long travel distances, and dispersed populations, despite relative economic standing and available resources.[2] New Zealand is one country where these natural and population features are a daily challenge to the timely and equitable delivery of prehospital emergency care.

Death and disability due to acute medical emergencies can be significantly reduced by the timely provision of prehospital emergency healthcare, thereby presenting many opportunities for tertiary prevention. Optimal models of trauma care delivery, focusing on a continuum of timely emergency medical services (EMS) to efficient in-hospital care, start with the rapid provision of prehospital EMS, provide the best chance for survival and rehabilitation following injury.[1 3 4] A time sensitive approach has also been proven to benefit patients requiring EMS following cardiac, stroke and vascular events.[5 6]

EMS are a vital entry point into the continuum of acute emergency health care, as their primary role is to rapidly meet the emergency prehospital care needs of patients following time-critical injury or health events. In terms of receiving hospital-level treatment, the first hour, commonly referred to as the 'golden hour', is generally considered to be the most critical in terms of receiving definitive treatment for cases with time-critical injuries or health conditions.[4] Although not supported by a strong evidence-base, access to EMS and advanced-level hospital care is often judged against this threshold.[7 8] Disparities in timely access to advanced-level hospitals have been documented in numerous countries, identifying higher risk of delayed access for communities and vulnerable groups.[7 9-12]

New Zealand's mountainous terrain, long travel distances, and relatively small and geographically dispersed population of 4.2 million can severely hinder physical/transport access to advanced hospital-level care impacting timely and equitable delivery of prehospital EMS. New Zealand's population density is relatively low at 15 people per square kilometre, considerably less than countries with similar land area such as the United Kingdom with 243 people per square kilometre. Despite having low overall population density, New Zealand is highly urbanised, with 86% of the population living in urban areas.[13] Case reviews in New

Zealand suggest there are opportunities to improve prehospital EMS and reduce the number of prehospital deaths.[14 15]

This study systematically examines geographical proximity and access to prehospital care provided by EMS and advanced-level hospital care, for the smallest geographical units used in New Zealand, in order to identify opportunities to improve survivability and reduce disability following time-critical medical emergencies, and explores national disparities in geographical access to these services.

METHODS

Advanced level hospital care in New Zealand

There are three levels of classification for New Zealand hospitals, relating to their capability to provide the appropriate services for seriously injured or ill patients (Table 1). New Zealand has a unique system where by trauma response, treatment, and rehabilitation are funded by the universal, no-fault, publicly funded Accident Compensation Corporation (ACC). In contrast, medical response, treatment and rehabilitation is publicly funded by each individual District Health Board with some part-charges for ambulance services.

Data sources

For this study we used Census 2013 (most recent publically available data) meshblock boundary and characteristics information available from Statistics New Zealand.[16] Meshblocks are the smallest geographical unit available. In the 2013 census there were 45,989 meshblocks ranging in size from part of a city block containing approximately 110 people to a large area of rural land containing approximately 60 people. In addition to the boundary shapefiles, we obtained sociodemographic, deprivation and urbanity characteristics of the population usually residing within each meshblock.[16]

The physical addresses of advanced-level (Level 1 and 2) hospitals were converted to geographical longitude-latitude coordinates. The locations of road ambulance stations as at 2014/15 were obtained from the two providers of these services in New Zealand, St. John Ambulance (New Zealand's major provider serving 98% of the population) and Wellington Free Ambulance. Air EMS services were restricted to helicopter based services in use in 2016 and their longitude-latitude coordinates were derived from multiple sources, including the Civil Aviation Authority, the Hawkes Bay Rescue Helicopter Trust, and Google Maps. Road

network data was obtained from www.geofabrik.de, an online open street map and spatial data provider.

Geospatial access calculations

The continuous access times were categorised using relatively fine-grained (<30, 30-45, 45-60, 60-90, ≥90) categories for descriptive purposes and to ensure the use of the 'golden hour' was sensible for the NZ population. Timely access was defined as the proportion of the population or land area from which an injured person was theoretically able to reach an advanced-level hospital within a given time of 60 minutes via air and road EMS. Access was calculated using established geospatial methods previously described elsewhere.[7 17] The time required for the nearest air or road EMS to reach the geometric centroid of a meshblock, stabilise a patient, and then travel to the nearest advanced-level hospital was calculated for every meshblock.

Road network travel times included the following assumption obtained from St Johns: immediate response and average road ambulance time at scene 14 minutes and 49 seconds. Road ambulance drive times were calculated using the Open Source Routing Machine (OSRM available at www.project-osrm.org). A detailed description on how spatial data are modelled in OSRM is available elsewhere.[18] All road calculations assumed ambulances drove at legal road speed, did not stop at intersections, driving conditions were ideal (i.e. no congestion), and ambulances drove the shortest route.

Air EMS travel times assumed helicopters flew in straight lines at an operational speed of 182 km/hour, response time (preparation for lift-off) of 8 minutes, on scene time of 27 minutes and 28 seconds, plus 32 seconds to find a safe pick-up landing site.[19] Air EMS flight times were calculated using custom written Python code running inside QGIS software.

Sociodemographic variables

Sociodemographic data on age, sex and ethnicity was obtained by summing the subtotal of each characteristic across all meshblocks, thus estimating the population of New Zealand at the time of the 2013 Census. Age was grouped into five categories: 0-14, 15-29, 30-44, 45-64 and ≥65 years. The five categories of ethnicity used were: Māori (Indigenous population), Pacific, Asian, New Zealand European, and MELAA (Middle Eastern, Latin American, African) and Other. Census ethnicity data is not prioritised, with individuals able to record multiple ethnicities, therefore all ethnicities reported are counted resulting in totals greater than 100%.

Deprivation was derived using the 2013 New Zealand Deprivation Index (NZDep), which aggregates and ranks communication, income, employment, family support, qualifications, home ownership, living space and transport within each meshblock area.[20] NZDep deciles were categorised into quintiles, with '1-2' representing the least deprived 20% and '9-10' the most deprived 20% of meshblocks in New Zealand. Population density within each meshblock area was calculated using number of usually resident people divided by meshblock area, grouped into three categories: high (20 to <200,000), medium (2 to <20) and low (0 to <2 persons per kilometre^2).

Statistical analyses

Our unit of analysis was the 2013 Census meshblock. The count of usually resident populations within each Census 2013 meshblock was summed across the country to obtain national denominators. The sociodemographic, deprivation and urbanity characteristics of the population unable to access advanced-level care within key times are described using row percentages. Binomial exact 95% confidence intervals were calculated for row percentages using Stata version 13 SE.

A map of New Zealand was created to provide a visual representation of the areas within New Zealand that cannot access advanced-level hospital care via air and road EMS within 60 minutes.

Patient and public involvement.

This study is a theoretical modelling geospatial analysis with no direct contact with study participants or patients or the public thus they were not involved in: 1) developing the research question and outcome measures; 2) planning the study design; and 3) the recruitment and conduct of the study. A study advisory group included patient and client representatives from SafeKids New Zealand, St Johns New Zealand, Pacifica Injury Prevention Aukilana (PIPA), Fire and Emergency New Zealand, Accident Compensation Corporation, and National Ambulance Sector Office. Dissemination of the study's findings will include meetings where patients/public and community groups engage, including the public health and injury prevention and control meetings.

Ethical Approval

Ethical approval for the broader programme of research[17], of which this specific study is a part of, was obtained from the University of Auckland Human Participants Ethics Committee (ref 016179), National Coronial Information System (ref NZ007) and University of Otago Health and Disability Ethics Committee (ref OTA/90/02/008/AM05).

RESULTS

Access to advanced-level hospital care by air or road EMS takes over 60 minutes for the majority (84%) of New Zealand's land area:. While less than 16% of our land area allows emergency access via road or air (3.5% accessible by road only and 15% by air only) within 60 minutes, a substantial majority (83%) of New Zealanders live within those areas that do have timely access to advanced hospital level care within 60 minutes (Table 2). Close to one quarter (24%) of New Zealanders are estimated to have access to advanced-level hospital care within 30 minutes and two thirds (66%) within 45 minutes, 13% of the population are estimated to take up to 30 minutes longer than the 'golden hour' (i.e. within 60-90 minutes), and 4% are estimated to take greater than 90 minutes to access to advanced level hospital care.

Significant population differences in timely access were observed by ethnicity and population density. Persons identifying with the Asian ethnic group have the best theoretical access to hospital level care, with only 0.78% residing in meshblocks greater than 90 minutes away from Level 1 or 2 hospital care. In contrast, those of Māori ethnicity had the poorest level of access with 4% living in meshblocks greater than 90 minutes away from advanced-level hospital care (difference in proportion 3.22%, 95% CI 2.19,4.48) . With respect to population density, access was poorest for people usually residing in lower density areas meshblocks, with 27% of people usually resident in low density areas versus 2% of people usually resident in high density areas being greater than 90 minutes away from either Level 1 or 2 hospital care (difference in proportion 25%, 95% CI 22, 27).

Timely geographical access to our most advanced Level 1 hospital care is poorest for those aged 65 years or greater, those of Māori, New Zealand European, and Other ethnic groups, residents with high levels of deprivation, and those usually residing in the central North Island and lower South Island (Table 3). The addition of regional Level 2 hospital care significantly expands the catchment from 59.8% (95% CI 56.7, 62.9) of the population residing in meshblocks with access to advanced-level hospital care (Level 1 and 2) within 60 minutes to 84.6% (95% CI 82.2, 86.8) (Table 3). In terms of land area access this equates to 5% (95% CI 4,7) of New Zealand's total land area with timely access to Level 1 hospital care within 60 minutes, which increases to 16% (95% CI 14,18) with the addition of Level 2 hospital care (results not in table).

Sub-population differences exist in timely access observed by age, ethnicity, level of deprivation and population density (Table 3). The oldest New Zealanders (65+ year olds) have the least access to Level 1 (5.7%, 95% CI 47.6, 53.8) and combined Level 1 and 2 hospital care (79.4%, 95% CI 76.8, 81.9). Less than half of the Māori population (45.6%, 95% CI 42.5, 48.7) reside in geographical areas with timely theoretical access to Level 1 hospital care, increasing to 78.7% (95% CI 76.0, 81.2) with the inclusion of Level 2 hospital care, but still significantly lower than the Pacific, Asian and MELAA other ethnic groups. Geographical areas with timely theoretical access to hospital care have a high proportion of resident Asian, Pacific and MELAA ethnic groups. The proportion of the population with timely access to advanced-level hospital care declines with increasing levels of deprivation, the exception to this is the most deprived group (NZ Dep 9-10) for whom access increased slightly from the previous level of NZ Dep 7-8, reflecting many of highly deprived areas in New Zealand are located in main urban areas close to hospitals. Those residing in meshblock areas with the least deprivation have a significantly better degree of timely access. Regions with low to medium population density have the poorest access to prehospital care, with a paltry 2.8% (95% CI 1.8, 4.0) of those usually residing in areas of low population density having access to a Level 1 hospital, expanding to 15.2% (95% CI 13.0, 17.6) with the inclusion of Level 2 care. No differences were observed by sex.

Figure 1 provides a visual representation of the catchment of air and road EMS given the placement of advanced-level hospitals and EMS bases. Comparing a) and c) provides some illustration of why timely access to usually resident population is high, but land area access is low. Timely access is clustered around the main highly populated areas with a population density in the range 20 to <200,000 people per kilometre. Air EMS services improve the level of timely access to advanced hospital level care above and beyond road EMS services in all areas except two in the lower South Island. However, much of the coverage is "doubled-up" as the combined road/air catchment closely follows the road only catchment. Many areas of moderate population density are not adequately covered by EMS, and the most isolated pockets of non-coverage are in areas with low population density.

DISCUSSION

This research examined the proportion of the usually resident population with theoretical timely access to advanced-level hospital care by air and road EMS in New Zealand and identified significant disparities in access to these prehospital services. Not surprisingly, timely access is clustered around areas of high population density based on where New Zealand's population usually resides. Applying the concept of the 'golden hour', we estimate 16% of the New Zealand population does not have timely theoretical access to advanced-level hospital care via road or air EMS. This equates to around 700,000 New Zealanders without timely access; particular disparities in theoretical timely access were observed for Māori, European New Zealanders, older New Zealanders and those residing in the lower South Island. Regionally based Level 2 hospital services are vital for rural communities to have timely access to care, particularly the Central North Island region where we estimate there is no timely access to the most advanced Level 1 hospital care within 60 minutes.

Previous international studies examining timely theoretical access to care following time-critical acute medical and trauma events have mainly focused on access to trauma services. Prehospital access to advanced trauma care in New Zealand is similar to that observed in the United States and Canada.[7 9 10] Timely access to advanced trauma care via road or air EMS was available to 88% of all United States residents, while 77% of Canadian residents have access via road ambulances.[9 10] Access to critical care services in Scotland is more comprehensive than New Zealand with 94% of the Scottish population within a 45 minute ambulance drive to definitive hospital-level care covering 47% of the Scottish landmass.[21] Unsurprisingly, the catchment of EMS and advanced-level hospital care aligns closely to population density in New Zealand, as also demonstrated in the United States, Canada and Scotland. Advanced-level hospital services are located to serve a large population base making the most efficient use of the resource and maintaining high levels of medical skill and management. This focus on areas of high population density, however, means that areas of disparities are generated on the basis of population density and dispersion. Areas of low to medium population density that have poorer EMS coverage typically have disproportionately greater indigenous Māori and ageing New Zealand European populations, high risk economic activity (such as farming and forestry), and remote areas of recreational and tourist activity.

Our study found significant socio-demographic disparities in timely theoretical access for indigenous Māori, New Zealand Europeans, older New Zealanders and those residing in the

southern part of the South Island, reflecting the geographical spread of New Zealand's population. While most Māori live in urban areas, Māori make up a higher proportion of the population residing in highly rural and remote areas, by contrast almost all Pacific and the majority of Asian people in New Zealand live in urban areas.[22] Older New Zealanders, who are typically New Zealand European, contribute to a high proportion of those who live in rural areas with low to moderate urban influence, explaining the longer theoretical access times observed for this group. Regions with low to moderate population density stood out as being significantly underserved when compared with areas of high population density. Similar disparities in access to advanced-level hospital care have been reported internationally for those residing in rural areas or very remote areas, and for ethnic minorities.[7 9-11 21] Our study provides further evidence of disparities in timely theoretical access to healthcare for Māori and for rural communities, and the unequal distribution of healthcare resources across New Zealand providing a further pathway for health disparities for Māori and rural populations: difficulties in achieved access to healthcare for these sub-groups are already well documented.[23 24] Our results add further support for EMS and advanced-level hospital services to be optimally configured to address both the geospatial and socio-demographic challenges of timely access relative to population density in New Zealand.

The optimal placement or enhancement of EMS retrieval and transfer services and advanced healthcare facilities in New Zealand should be examined further. One of the guiding principles for New Zealand's health system is that all New Zealanders have "timely and equitable access" to a "comprehensive range of health and disability services".[25] Our study found concerning geospatial disparities in timely geographical access for communities with low to moderate population density which tend to be rural and remote communities with disproportionately more Māori and older New Zealand Europeans. Furthermore areas with few permanent residents are popular destinations for international and residential tourists traveling to, and engaging in, outdoor tourist pursuits in remote back country and alpine areas. We have identified the need for the combined reach of EMS services and advanced-level hospital care to consider coverage of socio-demographic and geospatial aspects beyond just high density residential population bases.

Understanding the geospatial distribution of EMS services and timely access into advanced-level hospital care is the first step in identifying opportunities for improved care and planning of future services and health policy in the prehospital setting of an advanced trauma and

medical system. It is unknown if this current level of under-service results in higher rates of mortality across New Zealand, and future analyses from this research team will examine this question further with regard to injury.[17] Geographical areas with limited prehospital air and road EMS may be adequately served by other groups of appropriated trained first responders, such as General Practitioners, Police and Fire Services, where they sit outside of existing EMS catchment areas. Future research should examine the location of other first responders and the expansion of coverage of EMS these groups potentially provide. Other approaches to extending access to EMS and advanced-level hospital care include increasing, upgrading or integrating the roles of regional Level 3 hospitals in the provision of emergency care; expanding helicopter provision, repositioning existing road or air EMS depots, or providing novel methods such as delivery of advanced care to critically injured patients or telemedicine interventions.[7 10]

This study has a number of limitations. The choice of geospatial software and assumptions made are likely to impact the theoretical access estimates presented; we have consciously chosen conservative assumptions and settings meaning the proportion without timely access is likely to be underestimated. This analysis also assumes simultaneous dispatch by road and air EMS services, however the operational reality is that air response can take longer when emergency first responders are required to assess severity of an acute event prior to helicopter dispatch. It also assumes the availability of suitable helicopter landing sites at the meshblock centroid which may not be available. The benefits of the extended air ambulance coverage identified in our analysis would therefore only be achieved if air ambulance services were dispatched without delay and if suitable helicopter landing sites were available. Early/ simultaneous activation models have shown clear benefits for prevention of needless deaths.[26 27] A further limitation is that the EMS scenario theoretically modelled in our analysis fits a "scoop & run" strategy to prehospital care, and does not consider other prehospital strategies, such as a differentiated strategy, or rapid delivery of specialist medical expertise to the patient.[28] Recent empirical evidence suggests that a prehospital strategy should differentiate by injury type, with the worst case scenario injuries involving penetrating haemodynamically unstable injury or neurological trauma needing to reach advanced care as quickly as possible to have the best chance of survival.[29] The use of centroids may have led to geographic selection bias when a meshblock sits on edge of the time boundary, yet the centroid sits outside this boundary and is not selected. The potential for geographic selection bias is thought to be balanced out by the inclusion of similar sized meshblock's in close proximity with partial coverage over a time boundary where the centroid sits inside the boundary. Manual review of the 1044 large, remote meshblocks where the centroid was 10 km, or greater, from the nearest road revealed no part of these area units was reachable by air or road EMS within the time-limits examined.

Our study expands on previous geospatial examinations of access in New Zealand [30] and internationally [7 10 21] with the use of actual location of road and air based EMS services, with comparison to usually resident population densities, to assess the actual level of EMS coverage and response providing valuable geospatial analyses to inform future planning and expansion of prehospital EMS in New Zealand. As New Zealand is an island nation with a universal nationally funded health care system we are able to consider the closest hospital care without being restricted by State, Provincial or National funding boundaries, unlike some international studies.

Conclusion

Timely access to advanced-level hospital care is important to increase survival from time-critical acute injury and medical events. Our study highlights the need for planning of EMS coverage in New Zealand, especially for areas of moderate to low population density, in order to address inequities with regard to timely access to advanced-level hospital care. The geographical configuration of EMS and healthcare systems is important for optimising accessibility to services and promoting the efficient use of scarce resources in a geographically challenging island nation. Future analyses will examine if disparities in timely access to advanced-level hospital care translates into higher rates of mortality due to time critical injuries in New Zealand and identify areas requiring improved access to EMS and advanced-level hospital care relative to the burden of prehospital fatal injury.[17]

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Author contributors

R.L. contributed to the study design, conducted the literature review, provided oversight of the spatial analysis and was primarily responsible for the article preparation. B.dG. was primarily responsible for acquiring data and the spatial analysis, as well as contributing to the interpretation of data and preparation of the paper. G.D. contributed to the study design, provided advice on the spatial analysis methods, overseeing the spatial analysis and contributed to the interpretation of data and preparation of the paper. B.K. contributed to the study design, provided oversight of the project, interpretation of results and article preparation. C.B. contributed to the study design, provided advice on the spatial analysis methods and contributed to the direction of the analysis and interpretation of data and preparation of the paper. P.R., S.A, I.C., & B.D. contributed to the study design and to the interpretation of data and preparation of the paper.

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Competing Interests

The authors have no competing interests to declare.

Patient consent

Patient level data was not utilised in this study.

Ethics approval

Ethical approval for the broader programme of research[17], of which this specific study is a part of, was obtained from the University of Auckland Human Participants Ethics Committee (ref 016179), National Coronial Information System (ref NZ007) and University of Otago Health and Disability Ethics Committee (ref OTA/90/02/008/AM05).

Data sharing statement

Data are available from the corresponding author and access to these data will be considered on a case-by-case basis.

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Table 1. Categories of advanced levels of hospital care in New Zealand

Level of hospital care	**Services provided**	**Hospital locations**
Level 1	Advanced trauma and medical services based around comprehensive intensive care units with specialist staff.	Main population areas
Level 2	Capable of initial resuscitation and management. If specific intensive care not available then major trauma and severely ill patients transferred to Level 1 advanced care	Regional & rural provincial areas
Level 3	Run by non-specialist staff, capable of initial resuscitation. Major trauma and severely ill patients transferred to Level 1 advanced care.	Small rural areas

Table 2. Overall population and sub-population access to advanced-level hospital care by road and helicopter EMS within specified time periods.

Socio-demographic characteristics	**Population frequency**	**Have access to Level 1 or 2 hospital care within each specified period Minutes (row %)**				
		Within 30	**30-45**	**45-60**	**60-90**	**Greater than 90**
Total Population	4240791	24	42	17	13	4
Age (years)						
0-14	849192	22	44	19	13	4
15-29	829182	32	41	15	10	3
30-44	812718	25	44	17	11	4
45-64	1065417	22	42	19	14	4
≥65	605793	22	40	18	17	4
Sex						
Male	2061636	24	42	17	13	4
Female	2176134	24	42	18	13	4
Ethnicity*						
NZ European	2963721	22	40	19	15	3
Māori	595170	23	36	19	17	4
Pacific	295458	26	54	15	5	1
Asian	470793	32	57	7	3	1
MELAA	46905	31	52	9	5	2
Other	67398	24	42	17	13	3
Not Stated	235437	24	42	17	13	3
NZ Dep Index						
1-2 (least deprived)	873393	14	54	21	7	4
3-4	85626	19	45	19	14	4
5-6	837558	24	39	17	17	4
7-8	829704	32	35	15	16	4
9-10 (most)	833169	32	36	15	13	4
Population Density (persons per km^2)						
High (20-<200,000)	3859551	26	46	14	58	2
Medium (2-<20)	303696	0.3	8	37	45	10
Low (0-<2)	77544	0.015	1	14	57	27

* Multiple ethnic identities possible in Census, therefore, ethnic categories will add up to more than the total population

Table 3. Usually resident population access to different levels of advanced-level hospital care by road and helicopter EMS within specified time periods

Demographic characteristics	Level 1 hospital access Within 60 minutes		Level 1 & 2 hospital access Within 60 minutes	
	Row %	95% CI	Row %	95% CI
TOTAL	59.8	56.7, 62.9	84.6	82.2, 86.8
Age (years)				
0-14	59.8	56.7, 62.8	84.3	81.8, 86.5
15-29	67.3	64.3, 70.2	88.0	85.8, 89.9
30-44	64.3	61.2, 67.2	86.1	83.8, 88.2
45-64	58.0	54.9, 61.1	82.6	80.1, 84.9
65+	50.7	47.6, 53.8	79.4	76.8, 81.9
Sex				
Male	59.7	56.6, 62.8	83.4	80.9, 85.7
Female	59.9	56.8, 62.9	83.9	81.4, 86.1
Ethnicity				
New Zealand European	55.3	52.2, 58.4	81.5	78.9, 83.9
Māori	45.6	42.5, 48.7	78.7	76.0, 81.2
Pacific	84.4	82.0, 86.6	94.7	93.1, 96.0
Asian	87.4	85.1, 89.4	96.1	94.7, 97.2
MELAA	82.9	80.4, 85.2	93.0	91.2, 94.5
Other	52.7	49.6, 55.8	80.8	78.2, 83.2
Not stated	59.9	56.8, 62.9	83.7	81.2, 85.9
NZ Deprivation Index				
1-2 (least deprived)	73.4	70.5, 76.1	90.0	87.9, 91.8
3-4	62.0	58.9, 65.0	83.0	81.5, 85.3
5-6	54.9	51.8, 58.0	79.9	77.3, 82.3
7-8	53.9	50.8, 57.0	80.5	77.9, 82.9
9-10 (most deprived)	55.1	51.9, 58.2	83.6	81.2, 85.8
Population Density (persons per km^2)				
High (20-<200,000)	64.3	61.2, 67.2	88.0	85.8, 89.9
Medium (2-<20)	17.1	14.8, 19.6	45.3	42.2, 48.4
Low (0-<2)	2.8	1.8, 4.0	15.2	13.0, 17.6

Figure 1 legend

Figure 1. Access to advanced-level hospital care in New Zealand within 60 minutes. a: Population density. b: Road EMS coverage. c: Road or air EMS coverage.

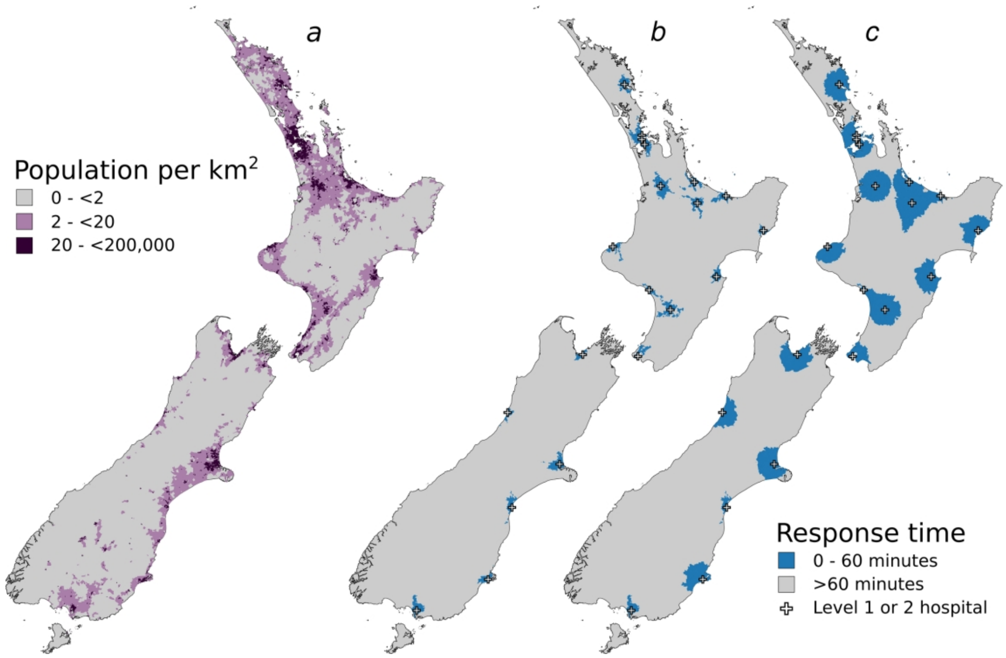

Figure 1. Access to advanced-level hospital care in New Zealand within 60 minutes. a: Population density. b: Road EMS coverage. c: Road or air EMS coverage.

196x127mm (300 x 300 DPI)

STROBE Statement: checklist of items included in reports of observational studies

	Item No	Recommendation	Check list
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	YES
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	YES
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	YES
Objectives	3	State specific objectives, including any prespecified hypotheses	YES
Methods			
Study design	4	Present key elements of study design early in the paper	YES
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	YES
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	N/A
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	YES
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	YES
Bias	9	Describe any efforts to address potential sources of bias	YES
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	YES
Statistical methods	12	(*a*) Describe all statistical methods, including control for confounding	YES
		(*b*) Describe any methods used to examine subgroups and interactions	YES
		(*c*) Explain how missing data were addressed	N/A
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	N/A

Results			Check list
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	YES
		(b) Indicate number of participants with missing data for each variable of interest	N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	YES
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	N/A
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	YES
Discussion			
Key results	18	Summarise key results with reference to study objectives	YES
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	YES
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	YES
Generalisability	21	Discuss the generalisability (external validity) of the study results	YES
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	YES

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Geographical and population disparities in timely access to prehospital and advanced level emergency care in New Zealand: a cross-sectional study

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Short: Disparities in access to prehospital trauma and medical care in NZ

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ABSTRACT

OBJECTIVE: Rapid access to advanced emergency medical and trauma care has been shown to significantly reduce mortality and disability. This study aims to systematically examine geographical access to prehospital care provided by Emergency Medical Services (EMS) and advanced-level hospital care, for the smallest geographical units used in New Zealand and explores national disparities in geographical access to these services.

DESIGN: Observational study involving geospatial analysis estimating population access to EMS and advanced-level hospital care.

SETTING: Population access to advanced-level hospital care via road and air EMS across New Zealand.

PARTICIPANTS: New Zealand population usually resident within geographical Census meshblocks.

PRIMARY AND SECONDARY OUTCOME MEASURES: The proportion of the resident population with calculated EMS access to advanced-level hospital care within 60 minutes was examined by age, sex, ethnicity, level of deprivation, and population density to identify disparities in geographical access.

RESULTS: An estimated 16% of the New Zealand population does not have timely EMS access to advanced-level hospital care via road or air. The 700,000 New Zealanders without timely access lived mostly in areas of low-moderate population density. Indigenous Māori, New Zealand European and older New Zealanders were less likely to have timely access.

CONCLUSIONS: These findings suggest that in New Zealand, geographically marginalised groups which tend to be rural and remote communities with disproportionately more indigenous Māori and older adults have poorer EMS access to advanced-level hospitals. Addressing these inequities in rapid access to medical care may lead to improvements in survival that have been documented for people who experience medical or surgical emergencies.

FUNDING: Health Research Council of New Zealand (HRC 15/186)

KEY WORDS: Emergency Medical Services; Geospatial; GIS; Hospital; Health Services Access; Time-to-treatment

Article Summary

Strengths and limitations of this study

This study is the first step in assessing access to emergency medical services (EMS) in New Zealand, a long, narrow and geographically challenging island nation in the South Pacific with a small, geographically dispersed population.

This study expands on previous international assessments of timely access to emergency hospital-level care by mapping exact locations of EMS response.

The choice of geospatial software and consciously conservative assumptions made are likely to underestimate the impact the access estimates presented.

The EMS scenario modelled in our analysis fits a theoretical "scoop & run" strategy to prehospital care, and does not consider other possible prehospital strategies, such as a differentiated strategy, or rapid delivery of specialist medical expertise to the patient.

INTRODUCTION

Globally, millions of people with life-threatening injuries or health events require timely access to advanced healthcare services, including prehospital emergency services, to prevent needless mortality and morbidity.[1] The public health burden of time-critical medical emergencies can be further exacerbated in countries with challenging terrain, long travel distances, and dispersed populations, despite relative economic standing and available resources.[2] New Zealand is one country where these natural and population features are a daily challenge to the timely and equitable delivery of prehospital emergency care.

Death and disability due to acute medical emergencies can be significantly reduced by the timely provision of prehospital emergency healthcare, thereby presenting many opportunities for tertiary prevention. Optimal models of trauma care delivery, focusing on a continuum of timely emergency medical services (EMS) to efficient in-hospital care, start with the rapid provision of prehospital EMS, provide the best chance for survival and rehabilitation following injury.[1 3 4] A time sensitive approach has also been proven to benefit patients requiring EMS following cardiac, stroke and vascular events.[5 6]

EMS are a vital entry point into the continuum of acute emergency health care, as their primary role is to rapidly meet the emergency prehospital care needs of patients following time-critical injury or health events. In terms of receiving hospital-level treatment, the first hour, commonly referred to as the 'golden hour', is generally considered to be the most critical in terms of receiving definitive treatment for cases with time-critical injuries or health conditions.[4] Although not supported by a strong evidence-base, access to EMS and advanced-level hospital care is often judged against this threshold.[7 8] Disparities in timely access to advanced-level hospitals have been documented in numerous countries, identifying higher risk of delayed access for communities and vulnerable groups.[7 9-12]

New Zealand's mountainous terrain, long travel distances, and relatively small and geographically dispersed population of 4.2 million can severely hinder physical/transport access to advanced hospital-level care impacting timely and equitable delivery of prehospital EMS. New Zealand's population density is relatively low at 15 people per square kilometre, considerably less than countries with similar land area such as the United Kingdom with 243 people per square kilometre. Despite having low overall population density, New Zealand is highly urbanised, with 86% of the population living in urban areas.[13] Case reviews in New

Zealand suggest there are opportunities to improve prehospital EMS and reduce the number of prehospital deaths.[14 15]

This study systematically examines geographical proximity and access to prehospital care provided by EMS and advanced-level hospital care, for the smallest geographical units used in New Zealand, in order to identify opportunities to improve survivability and reduce disability following time-critical medical emergencies, and explores national disparities in geographical access to these services.

METHODS

Advanced level hospital care in New Zealand

There are three levels of classification for New Zealand hospitals, relating to their capability to provide the appropriate services for seriously injured or ill patients (Table 1). New Zealand has a unique system where by trauma response, treatment, and rehabilitation are funded by the universal, no-fault, publicly funded Accident Compensation Corporation (ACC). In contrast, medical response, treatment and rehabilitation is publicly funded by each individual District Health Board with some part-charges for ambulance services.

Data sources

For this study we used Census 2013 (most recent publically available data) meshblock boundary and characteristics information available from Statistics New Zealand.[16] Meshblocks are the smallest geographical unit available. In the 2013 census there were 45,989 meshblocks ranging in size from part of a city block containing approximately 110 people to a large area of rural land containing approximately 60 people. In addition to the boundary shapefiles, we obtained sociodemographic, deprivation and urbanity characteristics of the population usually residing within each meshblock.[16]

The physical addresses of advanced-level (Level 1 and 2) hospitals were converted to geographical longitude-latitude coordinates. The locations of road ambulance stations as at 2014/15 were obtained from the two providers of these services in New Zealand, St. John Ambulance (New Zealand's major provider serving 98% of the population) and Wellington Free Ambulance. Air EMS services were restricted to helicopter based services in use in 2016 and their longitude-latitude coordinates were derived from multiple sources, including the Civil Aviation Authority, the Hawkes Bay Rescue Helicopter Trust, and Google Maps. Road

network data was obtained from www.geofabrik.de, an online open street map and spatial data provider.

Geospatial access calculations

The continuous access times were categorised using relatively fine-grained (<30, 30-45, 45-60, 60-90, ≥90 minutes) categories for descriptive purposes and to ensure the use of the 'golden hour' was sensible for the NZ population. Timely access was defined as the proportion of the population or land area from which an injured person was theoretically able to reach an advanced-level hospital within a given time of 60 minutes via air and road EMS. Access was calculated using established geospatial methods.[7 17] The time required for the nearest air or road EMS to reach the geometric centroid of a meshblock, stabilise a patient, and then direct travel to the nearest advanced-level receiving hospital was calculated for every meshblock.

Road network travel times included the following assumption obtained from St Johns: immediate response and average road ambulance time at scene 14 minutes and 49 seconds. Road ambulance drive times were calculated using the Open Source Routing Machine (OSRM available at www.project-osrm.org). A detailed description on how spatial data are modelled in OSRM is available elsewhere.[18] All road calculations assumed ambulances drove at legal road speed, did not stop at intersections, driving conditions were ideal (i.e. no congestion), and ambulances drove the shortest route.

Air EMS travel times assumed helicopters flew in straight lines at an operational speed of 182 km/hour, response time (preparation for lift-off) of 8 minutes, on scene time of 27 minutes and 28 seconds, plus 32 seconds to find a safe pick-up landing site.[19] Air EMS flight times were calculated using custom written Python code running inside QGIS software.

Sociodemographic variables

Sociodemographic data on age, sex and ethnicity was obtained by summing the subtotal of each characteristic across all meshblocks, thus estimating the population of New Zealand at the time of the 2013 Census. Age was grouped into five categories: 0-14, 15-29, 30-44, 45-64 and ≥65 years. The five categories of ethnicity used were: Māori (Indigenous population), Pacific, Asian, New Zealand European, and MELAA (Middle Eastern, Latin American, African) and Other. Census ethnicity data is not prioritised, with individuals able to record multiple ethnicities, therefore all ethnicities reported are counted resulting in totals greater than 100%.

Deprivation was derived using the 2013 New Zealand Deprivation Index (NZDep), which aggregates and ranks communication, income, employment, family support, qualifications, home ownership, living space and transport within each meshblock area.[20] NZDep deciles were categorised into quintiles, with '1-2' representing the least deprived 20% and '9-10' the most deprived 20% of meshblocks in New Zealand. Population density within each meshblock area was calculated using number of usually resident people divided by meshblock area, grouped into three categories: high (20 to <200,000), medium (2 to <20) and low (0 to <2 persons per kilometre^2).

Statistical analyses

Our unit of analysis was the 2013 Census meshblock. The count of usually resident populations within each Census 2013 meshblock was summed across the country to obtain national denominators. The sociodemographic, deprivation and urbanity characteristics of the population unable to access advanced-level care within key times are described using row percentages. Binomial exact 95% confidence intervals were calculated for row percentages using Stata version 13 SE.

A map of New Zealand was created to provide a visual representation of the areas within New Zealand that cannot access advanced-level hospital care via air and road EMS within 60 minutes. Where both air and road were viable options, the shorter time by whatever means was chosen.

Patient and public involvement.

This study is a theoretical modelling geospatial analysis with no direct contact with study participants or patients or the public thus they were not involved in: 1) developing the research question and outcome measures; 2) planning the study design; and 3) the recruitment and conduct of the study. A study advisory group included patient and client representatives from SafeKids New Zealand, St Johns New Zealand, Pacifica Injury Prevention Aukilana (PIPA), Fire and Emergency New Zealand, Accident Compensation Corporation, and National Ambulance Sector Office. Dissemination of the study's findings will include meetings where patients/public and community groups engage, including the public health and injury prevention and control meetings.

Ethical Approval

Ethical approval for the broader programme of research[17], of which this specific study is a part of, was obtained from the University of Auckland Human Participants Ethics Committee (ref 016179), National Coronial Information System (ref NZ007) and University of Otago Health and Disability Ethics Committee (ref OTA/90/02/008/AM05).

RESULTS

Access to advanced-level hospital care by air or road EMS takes over 60 minutes for the majority (84%) of New Zealand's land area:. While less than 16% of our land area allows emergency access via road or air (3.5% accessible by road only and 15% by air only) within 60 minutes, a substantial majority (83%) of New Zealanders live within those areas that do have timely access to advanced hospital level care within 60 minutes (Table 2). Close to one quarter (24%) of New Zealanders are estimated to have access to advanced-level hospital care within 30 minutes and two thirds (66%) within 45 minutes, 13% of the population are estimated to take up to 30 minutes longer than the 'golden hour' (i.e. within 60-90 minutes), and 4% are estimated to take greater than 90 minutes to access to advanced level hospital care.

Population differences in timely access were observed by ethnicity and population density. Persons identifying with the Asian ethnic group have the best estimated access to hospital level care, with only 0.78% residing in meshblocks greater than 90 minutes away from Level 1 or 2 hospital care. In contrast, those of Māori ethnicity had the poorest level of access with 4% living in meshblocks greater than 90 minutes away from advanced-level hospital care (difference in proportion 3.22%, 95% CI 2.19,4.48). With respect to population density, access was poorest for people usually residing in lower density areas meshblocks, with 27% of people usually resident in low density areas versus 2% of people usually resident in high density areas being greater than 90 minutes away from either Level 1 or 2 hospital care (difference in proportion 25%, 95% CI 22, 27).

Timely geographical access to our most advanced Level 1 hospital care is poorest for those aged 65 years or greater, those of Māori, New Zealand European, and Other ethnic groups, residents with high levels of deprivation, and those usually residing in the central North Island and lower South Island (Table 3). The addition of regional Level 2 hospital care significantly expands the catchment from 59.8% (95% CI 56.7, 62.9) of the population residing in meshblocks with access to advanced-level hospital care (Level 1 and 2) within 60 minutes to 84.6% (95% CI 82.2, 86.8) (Table 3). In terms of land area access this equates to 5% (95% CI 4,7) of New Zealand's total land area with timely access to Level 1 hospital care within 60 minutes, which increases to 16% (95% CI 14,18) with the addition of Level 2 hospital care (results not in table).

Sub-population differences exist in timely access observed by age, ethnicity, level of deprivation and population density (Table 3). The oldest New Zealanders (65+ year olds) have the least access to Level 1 (5.7%, 95% CI 47.6, 53.8) and combined Level 1 and 2 hospital care (79.4%, 95% CI 76.8, 81.9). Less than half of the Māori population (45.6%, 95% CI 42.5, 48.7) reside in geographical areas with timely access to Level 1 hospital care, increasing to 78.7% (95% CI 76.0, 81.2) with the inclusion of Level 2 hospital care, but still substantially lower than the Pacific, Asian and MELAA other ethnic groups. Geographical areas with timely theoretical access to hospital care have a high proportion of resident Asian, Pacific and MELAA ethnic groups. The proportion of the population with timely access to advanced-level hospital care declines with increasing levels of deprivation, the exception to this is the most deprived group (NZ Dep 9-10) for whom access increased slightly from the previous level of NZ Dep 7-8, reflecting many of highly deprived areas in New Zealand are located in main urban areas close to hospitals. Those residing in meshblock areas with the least deprivation have a substantially better degree of timely access. Regions with low to medium population density have the poorest access to prehospital care, with a paltry 2.8% (95% CI 1.8, 4.0) of those usually residing in areas of low population density having access to a Level 1 hospital, expanding to 15.2% (95% CI 13.0, 17.6) with the inclusion of Level 2 care. No differences were observed by sex.

Figure 1 provides a visual representation of the catchment of air and road EMS given the placement of advanced-level hospitals and EMS bases. Comparing a) and c) provides some illustration of why timely access to usually resident population is high, but land area access is low. Timely access is clustered around the main highly populated areas with a population density in the range 20 to <200,000 people per kilometre. Air EMS services improve the level of timely access to advanced hospital level care above and beyond road EMS services in all areas except two in the lower South Island. However, much of the coverage is "doubled-up" as the combined road/air catchment closely follows the road only catchment. Many areas of moderate population density are not adequately covered by EMS, and the most isolated pockets of non-coverage are in areas with low population density.

DISCUSSION

This research examined the proportion of the usually resident population with theoretical timely access to advanced-level hospital care by air and road EMS in New Zealand and identified important disparities in access to these prehospital services. Not surprisingly, timely access is clustered around areas of high population density based on where New Zealand's population usually resides. Applying the concept of the 'golden hour', we estimate 16% of the New Zealand population does not have timely theoretical access to advanced-level hospital care via road or air EMS. This equates to around 700,000 New Zealanders without timely access; particular disparities in theoretical timely access were observed for Māori, European New Zealanders, older New Zealanders and those residing in the lower South Island. Regionally based Level 2 hospital services are vital for rural communities to have timely access to care, particularly the Central North Island region where we estimate there is no timely access to the most advanced Level 1 hospital care within 60 minutes.

Previous international studies examining timely theoretical access to care following time-critical acute medical and trauma events have mainly focused on access to trauma services. Prehospital access to advanced trauma care in New Zealand is similar to that observed in the United States and Canada.[7 9 10] Timely access to advanced trauma care via road or air EMS was available to 88% of all United States residents, while 77% of Canadian residents have access via road ambulances.[9 10] Access to critical care services in Scotland is more comprehensive than New Zealand with 94% of the Scottish population within a 45 minute ambulance drive to definitive hospital-level care covering 47% of the Scottish landmass.[21] Unsurprisingly, the catchment of EMS and advanced-level hospital care aligns closely to population density in New Zealand, as also demonstrated in the United States, Canada and Scotland. Advanced-level hospital services are located to serve a large population base making the most efficient use of the resource and maintaining high levels of medical skill and management. This focus on areas of high population density, however, means that areas of disparities are generated on the basis of population density and dispersion. Areas of low to medium population density that have poorer EMS coverage typically have disproportionately greater indigenous Māori and ageing New Zealand European populations, high risk economic activity (such as farming and forestry), and remote areas of recreational and tourist activity.

Our study found important socio-demographic disparities in timely theoretical access for indigenous Māori, New Zealand Europeans, older New Zealanders and those residing in the

southern part of the South Island, reflecting the geographical spread of New Zealand's population. While most Māori live in urban areas, Māori make up a higher proportion of the population residing in highly rural and remote areas, by contrast almost all Pacific and the majority of Asian people in New Zealand live in urban areas.[22] Older New Zealanders, who are typically New Zealand European, contribute to a high proportion of those who live in rural areas with low to moderate urban influence, explaining the longer theoretical access times observed for this group. Regions with low to moderate population density stood out as being significantly underserved when compared with areas of high population density. Similar disparities in access to advanced-level hospital care have been reported internationally for those residing in rural areas or very remote areas, and for ethnic minorities.[7 9-11 21] Our study provides further evidence of disparities in timely theoretical access to healthcare for Māori and for rural communities, and the unequal distribution of healthcare resources across New Zealand providing a further pathway for health disparities for Māori and rural populations: difficulties in achieved access to healthcare for these sub-groups are already well documented.[23 24] Our results add further support for EMS and advanced-level hospital services to be optimally configured to address both the geospatial and socio-demographic challenges of timely access relative to population density in New Zealand.

The optimal placement or enhancement of EMS retrieval and transfer services and advanced healthcare facilities in New Zealand should be examined further. One of the guiding principles for New Zealand's health system is that all New Zealanders have "timely and equitable access" to a "comprehensive range of health and disability services".[25] Our study found concerning geospatial disparities in timely geographical access for communities with low to moderate population density which tend to be rural and remote communities with disproportionately more Māori and older New Zealand Europeans. Furthermore areas with few permanent residents are popular destinations for international and residential tourists traveling to, and engaging in, outdoor tourist pursuits in remote back country and alpine areas. We have identified the need for the combined reach of EMS services and advanced-level hospital care to consider coverage of socio-demographic and geospatial aspects beyond just high density residential population bases.

Understanding the geospatial distribution of EMS services and timely access into advanced-level hospital care is the first step in identifying opportunities for improved care and planning of future services and health policy in the prehospital setting of an advanced trauma and

medical system. It is unknown if this current level of under-service results in higher rates of mortality across New Zealand, and future analyses from this research team will examine this question further with regard to injury.[17] Geographical areas with limited prehospital air and road EMS may be adequately served by other groups of appropriated trained first responders, such as General Practitioners, Police and Fire Services, where they sit outside of existing EMS catchment areas. Future research should examine the location of other first responders and the expansion of coverage of EMS these groups potentially provide. Other approaches to extending access to EMS and advanced-level hospital care include increasing, upgrading or integrating the roles of regional Level 3 hospitals in the provision of emergency care; expanding helicopter provision, repositioning existing road or air EMS depots, or providing novel methods such as delivery of advanced care to critically injured patients or telemedicine interventions.[7,10]

This study has a number of limitations. The choice of geospatial software and assumptions made are likely to impact the theoretical access estimates presented; we have consciously chosen conservative assumptions and settings meaning the proportion without timely access is likely to be underestimated. This analysis also assumes simultaneous dispatch by road and air EMS services, however the operational reality is that air response can take longer when emergency first responders are required to assess severity of an acute event prior to helicopter dispatch. It also assumes the availability of suitable helicopter landing sites at the meshblock centroid which may not be available. The benefits of the extended air ambulance coverage identified in our analysis would therefore only be achieved if air ambulance services were dispatched without delay and if suitable helicopter landing sites were available. Early/simultaneous activation models have shown clear benefits for prevention of needless deaths.[26,27] A further limitation is that the EMS scenario theoretically modelled in our analysis fits a "scoop & run" strategy to prehospital care, and does not consider other possible regional or local prehospital and EMS strategies, such as a differentiated strategy, or rapid delivery of specialist medical expertise to the patient.[28] Recent empirical evidence suggests that a prehospital strategy should differentiate by injury type, with the worst case scenario injuries involving penetrating haemodynamically unstable injury or neurological trauma needing to reach advanced care as quickly as possible to have the best chance of survival.[29] The use of centroids may have led to geographic selection bias when a meshblock sits on edge of the time boundary, yet the centroid sits outside this boundary and is not selected. The potential for geographic selection bias is thought to be balanced out by the inclusion of similar sized meshblock's in close proximity with partial coverage over a time boundary where the centroid sits inside the boundary. Manual review of the 1044 large, remote meshblocks where the centroid was 10 km, or greater, from the nearest road revealed no part of these area units was reachable by air or road EMS within the time-limits examined.

Our study expands on previous geospatial examinations of access in New Zealand [30] and internationally [7 10 21] with the use of actual location of road and air based EMS services, with comparison to usually resident population densities, to assess the actual level of EMS coverage and response providing valuable geospatial analyses to inform future planning and expansion of prehospital EMS in New Zealand. As New Zealand is an island nation with a universal nationally funded health care system we are able to consider the closest hospital care without being restricted by State, Provincial or National funding boundaries, unlike some international studies.

Conclusion

Timely access to advanced-level hospital care is important to increase survival from time-critical acute injury and medical events. Our study highlights the need for planning of EMS coverage in New Zealand, especially for areas of moderate to low population density, in order to address inequities with regard to timely access to advanced-level hospital care. The geographical configuration of EMS and healthcare systems is important for optimising accessibility to services and promoting the efficient use of scarce resources in a geographically challenging island nation. Future analyses will examine if disparities in timely access to advanced-level hospital care translates into higher rates of mortality due to time critical injuries in New Zealand and identify areas requiring improved access to EMS and advanced-level hospital care relative to the burden of prehospital fatal injury.[17]

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Author contributors

R.L. contributed to the study design, conducted the literature review, provided oversight of the spatial analysis and was primarily responsible for the article preparation. B.dG. was primarily responsible for acquiring data and the spatial analysis, as well as contributing to the interpretation of data and preparation of the paper. G.D. contributed to the study design, provided advice on the spatial analysis methods, overseeing the spatial analysis and contributed to the interpretation of data and preparation of the paper. B.K. contributed to the study design, provided oversight of the project, interpretation of results and article preparation. C.B. contributed to the study design, provided advice on the spatial analysis methods and contributed to the direction of the analysis and interpretation of data and preparation of the paper. P.R., S.A, I.C., & B.D. contributed to the study design and to the interpretation of data and preparation of the paper.

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Competing Interests

The authors have no competing interests to declare.

Patient consent

Patient level data was not utilised in this study.

Ethics approval

Ethical approval for the broader programme of research[17], of which this specific study is a part of, was obtained from the University of Auckland Human Participants Ethics Committee (ref 016179), National Coronial Information System (ref NZ007) and University of Otago Health and Disability Ethics Committee (ref OTA/90/02/008/AM05).

Data sharing statement

Data are available from the corresponding author and access to these data will be considered on a case-by-case basis.

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Table 1. Categories of advanced levels of hospital care in New Zealand

Level of hospital care	**Services provided**	**Hospital locations**
Level 1	Advanced trauma and medical services based around comprehensive intensive care units with specialist staff.	Main population areas
Level 2	Capable of initial resuscitation and management. If specific intensive care not available then major trauma and severely ill patients transferred to Level 1 advanced care	Regional & rural provincial areas
Level 3	Run by non-specialist staff, capable of initial resuscitation. Major trauma and severely ill patients transferred to Level 1 advanced care.	Small rural areas

Table 2. Overall population and sub-population access to advanced-level hospital care by road and helicopter EMS within specified time periods.

Socio-demographic characteristics	**Population frequency**	**Have access to Level 1 or 2 hospital care within each specified period Minutes (row %)**				
		Within 30	**30-45**	**45-60**	**60-90**	**Greater than 90**
Total Population	4240791	24	42	17	13	4
Age (years)						
0-14	849192	22	44	19	13	4
15-29	829182	32	41	15	10	3
30-44	812718	25	44	17	11	4
45-64	1065417	22	42	19	14	4
≥65	605793	22	40	18	17	4
Sex						
Male	2061636	24	42	17	13	4
Female	2176134	24	42	18	13	4
Ethnicity*						
NZ European	2963721	22	40	19	15	3
Māori	595170	23	36	19	17	4
Pacific	295458	26	54	15	5	1
Asian	470793	32	57	7	3	1
MELAA	46905	31	52	9	5	2
Other	67398	24	42	17	13	3
Not Stated	235437	24	42	17	13	3
NZ Dep Index						
1-2 (least deprived)	873393	14	54	21	7	4
3-4	85626	19	45	19	14	4
5-6	837558	24	39	17	17	4
7-8	829704	32	35	15	16	4
9-10 (most)	833169	32	36	15	13	4
Population Density (persons per km^2)						
High (20-<200,000)	3859551	26	46	14	58	2
Medium (2-<20)	303696	0.3	8	37	45	10
Low (0-<2)	77544	0.015	1	14	57	27

* Multiple ethnic identities possible in Census, therefore, ethnic categories will add up to more than the total population

Table 3. Usually resident population access to different levels of advanced-level hospital care by road and helicopter EMS within specified time periods

Demographic characteristics	**Level 1 hospital access Within 60 minutes**		**Level 1 & 2 hospital access Within 60 minutes**	
	Row %	**95% CI**	**Row %**	**95% CI**
TOTAL	59.8	56.7, 62.9	84.6	82.2, 86.8
Age (years)				
0-14	59.8	56.7, 62.8	84.3	81.8, 86.5
15-29	67.3	64.3, 70.2	88.0	85.8, 89.9
30-44	64.3	61.2, 67.2	86.1	83.8, 88.2
45-64	58.0	54.9, 61.1	82.6	80.1, 84.9
65+	50.7	47.6, 53.8	79.4	76.8, 81.9
Sex				
Male	59.7	56.6, 62.8	83.4	80.9, 85.7
Female	59.9	56.8, 62.9	83.9	81.4, 86.1
Ethnicity				
New Zealand European	55.3	52.2, 58.4	81.5	78.9, 83.9
Māori	45.6	42.5, 48.7	78.7	76.0, 81.2
Pacific	84.4	82.0, 86.6	94.7	93.1, 96.0
Asian	87.4	85.1, 89.4	96.1	94.7, 97.2
MELAA	82.9	80.4, 85.2	93.0	91.2, 94.5
Other	52.7	49.6, 55.8	80.8	78.2, 83.2
Not stated	59.9	56.8, 62.9	83.7	81.2, 85.9
NZ Deprivation Index				
1-2 (least deprived)	73.4	70.5, 76.1	90.0	87.9, 91.8
3-4	62.0	58.9, 65.0	83.0	81.5, 85.3
5-6	54.9	51.8, 58.0	79.9	77.3, 82.3
7-8	53.9	50.8, 57.0	80.5	77.9, 82.9
9-10 (most deprived)	55.1	51.9, 58.2	83.6	81.2, 85.8
Population Density (persons per km^2)				
High (20-<200,000)	64.3	61.2, 67.2	88.0	85.8, 89.9
Medium (2-<20)	17.1	14.8, 19.6	45.3	42.2, 48.4
Low (0-<2)	2.8	1.8, 4.0	15.2	13.0, 17.6

Figure 1 legend

Figure 1. Access to advanced-level hospital care in New Zealand within 60 minutes. a: Population density. b: Road EMS coverage. c: Road or air EMS coverage.

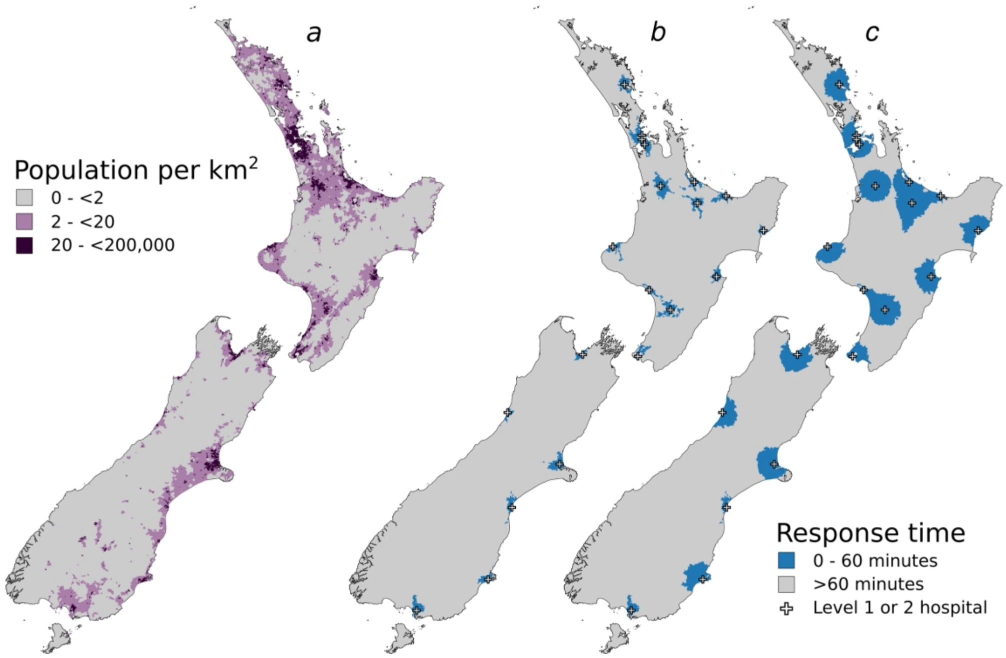

Figure 1. Access to advanced-level hospital care in New Zealand within 60 minutes. a: Population density. b: Road EMS coverage. c: Road or air EMS coverage.

196x127mm (300 x 300 DPI)

STROBE Statement: checklist of items included in reports of observational studies

	Item No	Recommendation	Check list
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Yes
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Yes
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Yes p5-6
Objectives	3	State specific objectives, including any prespecified hypotheses	Yes p6
Methods			
Study design	4	Present key elements of study design early in the paper	Yes p6-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Yes p6-8
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	N/A
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	N/A
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Y p6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Y p6-8
Bias	9	Describe any efforts to address potential sources of bias	Y p6-8
Study size	10	Explain how the study size was arrived at	N/A
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Y p8
Statistical methods	12	(*a*) Describe all statistical methods, including control for confounding	Y p8
		(*b*) Describe any methods used to examine subgroups and interactions	Y p8
		(*c*) Explain how missing data were addressed	N/A
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	N/A
		(*e*) Describe any sensitivity analyses	N/A

Results			Check list
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	N/A
		(b) Give reasons for non-participation at each stage	N/A
		(c) Consider use of a flow diagram	N/A
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Y p
		(b) Indicate number of participants with missing data for each variable of interest	N/A
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	N/A
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	N/A
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	N/A
		Cross-sectional study—Report numbers of outcome events or summary measures	Yes p9
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	N/A
		(*b*) Report category boundaries when continuous variables were categorized	N/A
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	N/A
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Yes p9-10
Discussion			
Key results	18	Summarise key results with reference to study objectives	Yes p11
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Yes p13
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Yes p11-13
Generalisability	21	Discuss the generalisability (external validity) of the study results	Yes p11
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Yes p15