

Geographical access to critical care services in Scotland

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Abstract

Background: Critical illness requires specialist and timely management. The aim of this study was to create a geographic accessibility profile of the Scottish population to emergency departments and intensive care units.

Methods: This was a descriptive, geographical analysis of population access to ‘intermediate’ and ‘definitive’ critical care services in Scotland. Access was defined by the number of people able to reach services within 45 to 60 min, by road and by helicopter. Access was analysed by health board, rurality and as a country using freely available geographically referenced population data.

Results: Ninety-six percent of the population reside within a 45-min drive of the nearest intermediate critical care facility, and 94% of the population live within a 45-min ambulance drive time to the nearest intensive care unit. By helicopter, these figures were 95% and 91%, respectively. Some health boards had no access to definitive critical care services within 45 min via helicopter or road. Very remote small towns and very remote rural areas had poorer access than less remote and rural regions.

Keywords

Intensive care, GIS, access, Scotland

Introduction

Critical illness requires specialist care, which is typically not available in all hospitals. Delayed access to services has been shown to be associated with increased mortality and hospital length of stay.^{1–3} Ensuring equity of access is a key objective for health-care systems,⁴ and quantifying the geographic accessibility of the population to critical care services plays an important role in this.

Previous evaluations of geographical accessibility have focused on specific conditions, or certain services. Wallace et al.⁵ conducted an evaluation of geographical access to severe acute respiratory failure centres in the United States, which revealed wide variation across states and regions. There have been evaluations of the accessibility to burn,⁶ trauma and neurosurgical centres in the United States and Canada,^{7–10} and trauma care in the United Kingdom.^{11,12} However, all of these studies considered isolated aspects of accessibility, rather than providing a comprehensive profile of access to critical care services.

The aim of this study was to conduct a population-based analysis of geographical access to critical care

services in Scotland, with particular reference to the effects of rurality and inter-regional variations. Scotland has excellent geographically referenced population data, and a highly granular classification of rurality, facilitating such an evaluation.

Scotland has a mixed urban/rural population, with large cities as well as areas of low population density. The recently published National Clinical Strategy sets out a framework for the development of health services across Scotland for the next 15 years.¹³

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It emphasises the importance of planning services at a population level and the development of hospital networks to deliver complex care. The accessibility of critical care services, across Scotland as a whole, has not previously been analysed in this context.

Methods

Study design

This is a geographical analysis of population and areal coverage. Geographical accessibility was defined as the percentage of the population that could reach a critical care service within a certain time (45 or 60 min), and the percentage of land area from which a hospital with a critical care service could be reached within this time.

Setting

Scotland has a land area of 78,770 km², constituting approximately one-third of the United Kingdom's land mass, and a population of 5.4 million.¹⁴ Eighty-one percent of the Scottish population live in urban areas, predominantly in the so-called 'Central Belt', which extends from Glasgow in the West to Edinburgh in the East, and the coastal areas in the East and North East. Large areas, predominantly in the mountainous West and North West, are sparsely populated, with among the lowest population densities in Europe (Figure 1).¹⁴ Scotland has 790 islands, although only 95 are inhabited. The combined population of the Scottish islands is 103,000.¹⁵

Administrative regions and rurality

We analysed access for the population and country as a whole, as well as by administrative area (health board region), and rurality. There are 14 boards, of varying size, which are responsible for the delivery of healthcare services (Figure 1 and Table 1). Scotland has an established urban/rural classification scheme.¹⁶ The latest, eight-fold version of the classification divides the country into large urban areas, other urban areas, accessible small towns, remote small towns, very remote small towns, accessible rural areas, remote rural areas and very remote rural areas using a combination of settlement size and drive time (Supplementary Table 5).

Classification of critical care services

The Scottish Intensive Care Society audit group (SICSAG) lists 26 intensive care units (ICUs), in 23 hospitals.¹⁷ Most of these centres are University-affiliated hospitals or large district general hospitals located in areas of high population density. However, critical care is not only provided in ICUs - most emergency departments have the ability to intubate

patients, and commence ventilatory and cardiovascular support, but other treatments, such as renal replacement therapy or intracranial pressure monitoring, are generally only available in ICUs. Critical care services were therefore defined as either 'intermediate' or 'definitive'. Intermediate critical care was defined as the ability to provide advanced airway management, including drug-assisted intubation, cardiovascular monitoring with central and arterial lines and vasoactive drug treatment. This level of care would be expected in most emergency departments, even when hospitals do not have critical care ward facilities. Definitive critical care was defined as the level of care which would be expected from an ICU, including advanced respiratory and circulatory support, and renal replacement therapy, equating to level 3 critical care, as defined by the Intensive Care Society.¹⁸

Identification and geocoding of hospitals

We used reports from audit Scotland¹⁹ and SICSAG¹⁷ to identify centres which provide such services and to classify them. Thirty hospitals were identified, of which 20 have definitive critical care facilities. A further 10 offer intermediate services only. This study was focused on adult services, and we therefore excluded the two paediatric ICUs and a stand-alone specialist cardiothoracic ICU. The hospitals' locations were georeferenced using Google maps.²⁰ The WGS 1984 co-ordinate system was used throughout.

Helicopter locations

The Scottish Ambulance Service has three EC-145 helicopters, based in Glasgow, Perth and Inverness (Figure 2). The longitude and latitude of these locations were, again, determined using Google maps.²⁰

Access time threshold

The analyses are based on an 'access time threshold', defined as the time within which a patient can reach a desired level of care, from the point of being ready to depart from the patient's location. This concept is widely used by trauma networks,^{7,10} but there is presently no equivalent guidance specifically relating to critically ill patients. The Scottish Trauma Network operates with a 45-min access time threshold,²¹ and we therefore used this figure for our primary analysis. However, other trauma systems use a 60-min threshold, and the National Institute for Health and Clinical Excellence has recently advocated for a lengthening of the trauma network access time thresholds,²² based on experiences in England. We have, therefore, included a sensitivity analysis, using the 60-min threshold, as supplementary data.

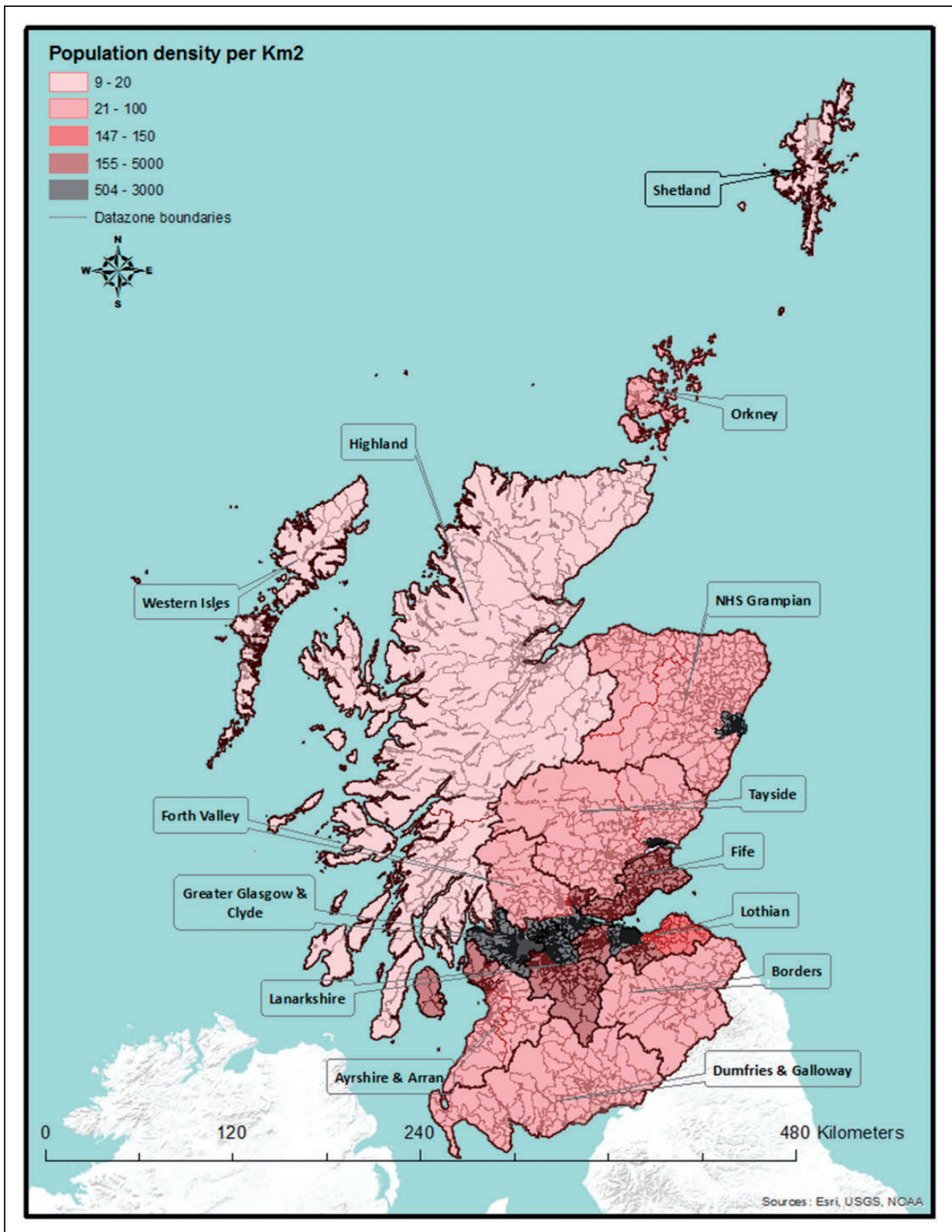


Figure 1. Population density in Scotland with datazones underlain.

Isochrone derivation

An area which can be reached from a central location within a set time, or from which a central location can be reached, is referred to as an isochrone.

Drive-time isochrones. For each hospital 45 and 60 min drive time isochrones were determined using 'blue light' travel times, defined as the speed limit plus 10mph to simulate road ambulance travel. The drive-time isochrone calculations were performed by

Table 1. Accessibility by road ambulance: Population and areal coverage, by health board.

Health board	Intermediate critical care facilities				Definitive critical care facilities					
	Area	Population	Area	Population	Area	Population	Area	Population		
Name	km ²	n	km ²	%	n	%	km ²	%	n	%
Ayrshire and Arran	3369	373,339	3369	100	373,339	100	2835	84	366,827	98
Borders	4732	113,615	4334	92	110,238	97	4334	92	110,238	97
Dumfries and Galloway	6426	151,302	6085	95	148,441	98	4672	73	121,149	80
Fife	1325	367,036	1325	100	367,036	100	1325	100	367,036	100
Forth Valley	2643	297,529	2296	87	296,616	100	2204	83	296,470	100
Greater Glasgow and Clyde	1104	1,143,934	1104	100	1,143,934	100	1104	100	1,143,934	100
Grampian	8736	568,800	6571	75	538,979	95	4938	57	480,225	84
Highland	32,593	320,067	13,046	40	246,329	77	5603	17	175,841	55
Lanarkshire	2242	651,635	2242	100	651,635	100	2242	100	651,635	100
Lothian	1724	834,461	1724	100	834,461	100	1724	100	834,461	100
Orkney	990	21,349	457	46	16,512	77	0	0	0	0
Shetland	1467	23,154	598	41	14,919	64	0	0	0	0
Tayside	7527	409,481	5669	75	407,069	99	5660	75	407,063	99
Western Isles	3060	28,396	1172	38	18,019	63	0	0	0	0

an external company (Mercator GeoSystems, Sheffield, UK), and used to create ‘shapefiles’, a file format widely used by geographical information systems (GIS).

Flight-time isochrones. We assumed that critically ill patients would initially be attended by a road ambulance, or local practitioner, before calling a helicopter. This model broadly reflects current practice. The total time to reach a hospital therefore comprised the helicopter’s flight time to the patient’s location, and the flight time from the patient’s location to hospital, as well as the start-up and loading times. The Scottish Ambulance Service’s helicopters are based at heliports, rather than hospitals, and the inbound and outbound flight times therefore differ, and the area from which a patient can be retrieved is defined by an ellipse, rather than a circle. The methodology used to calculate these ellipses is described in a previous publication.¹² We calculated the size, location and orientation of these ellipses for each of the 90 combinations of heliport and hospital. We assumed a helicopter cruising speed of 250 km/h, and a total of 15 min of start-up and loading time (i.e. 30-min and 45-min flying time, respectively); 30-min and 45-min flight times equate to ellipses with major radii of 125 and 187.5 km. Minor radii vary depending on the bearing between hospital and heliport, and the major value of the major radius.

Population data

The Scottish Government uses a small area geography referred to as ‘datazones’ for the dissemination of census and statistical data. Datazones correlate with

natural physical and societal boundaries, and have known populations, of between 500 and 1000 residents. These datazones and associated demographic data are freely available²³ (Figure 1).

Spatial analysis

The spatial analysis was conducted using ArcGIS 10.1 (ESRI®, Redlands, California), a GIS package. The drive-time and helicopter isochrones were overlain onto the datazone shapefiles, containing the demographic and geographical data, including health board boundaries and urban/rural classification. The number of residents and the geographical area beneath the drive-time isochrones was calculated using the intersect feature. Where datazones were split by drive time or helicopter boundaries, a polygon-in-polygon analysis was used to determine an average population per km² of that datazone. The new area was calculated, and from that, the population within the split polygon could be estimated. The sum of polygons was produced to give population and areas within a specified access time threshold to the nearest critical care service.

Results

Access to definitive critical care services

By road. Overall, 94% of the Scottish population live within a 45-min ambulance drive time of a definitive critical care service, but a 45-min drive time covers less than half of the Scottish landmass (47%).

Analysis by health board (Table 1) shows that regional population coverage varies from 0% to 100%.

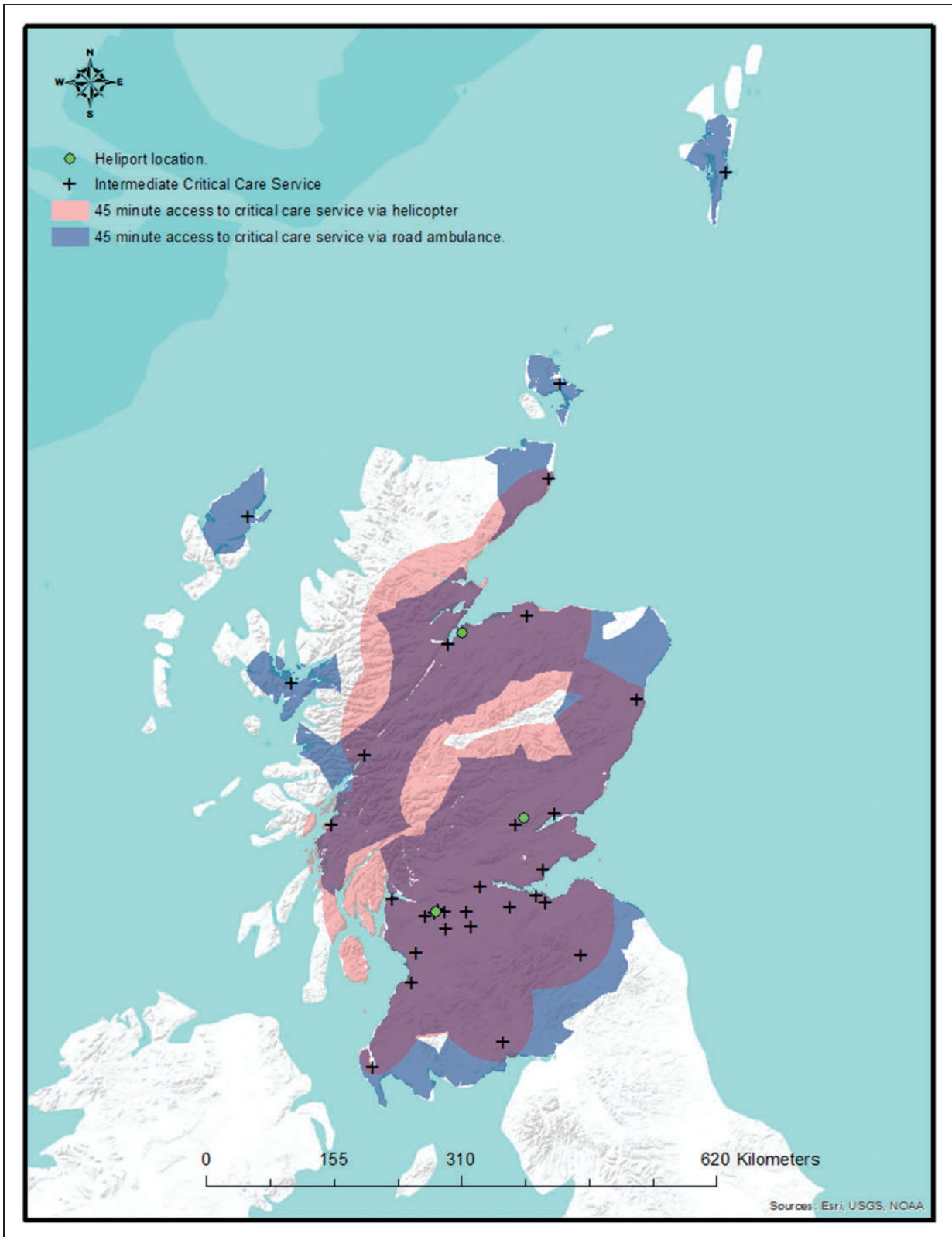


Figure 2. Location of critical care facilities, with 45-min drive times and 45-min helicopter access.

Fife, Forth Valley, Greater Glasgow and Clyde, Lanarkshire and Lothian health boards are able to provide complete population coverage. Ayrshire and Arran, Borders and Tayside health boards provide almost complete population coverage (98%, 97% and 99%, respectively), whereas coverage is lower in

Dumfries and Galloway (80%), Grampian (84%) and Highland (55%). Areal coverage (Table 1) is complete in Fife, Greater Glasgow and Clyde, Lanarkshire and Lothian, but less in Ayrshire and Arran (84%), the Borders (92%), Dumfries and Galloway (73%), Forth Valley (83%), Grampian (53%) and

Table 2. Accessibility by road ambulance: Population and areal coverage, by Scottish urban/rural classification category.

Health board	Intermediate critical care facilities				Definitive critical care facilities					
	Area	Population	Area	Population	Area	Population	Area	Population		
Name	km ²	n	km ²	%	n	%	km ²	%	n	%
Large urban areas	505	1,792,214	505	100	1,792,214	100	505	100	1,792,214	100
Other urban areas	691	1,780,740	690	100	1,778,865	100	673	97	1,759,115	99
Accessible small towns	188	451,419	188	100	451,419	100	186	99	444,448	98
Remote small towns	54	105,997	52	97	101,055	95	42	77	76,916	73
Very remote small towns	45	62,959	35	77	43,646	69	2	5	2789	4
Accessible rural areas	18,558	748,324	18,153	98	735,068	98	16,998	92	714,381	95
Remote rural areas	17,828	184,698	16,831	94	174,683	95	13,944	78	145,898	79
Very remote rural areas	40,066	176,503	13,467	34	90,632	51	4293	11	21,145	12

Highland (17%). The population of the islands (Orkney, Shetland and Western Isles health boards) do not have access to definitive critical care services within the 45-min access time threshold.

Analysis by rurality (Table 2) reveals that population coverage is complete in large urban areas, and almost complete in other urban areas (99%), accessible small towns (98%) and accessible rural areas (95%). Population coverage is lower in remote small towns (73%) and remote rural areas (79%) and very low in very remote small towns (4%) and very remote rural areas (12%). Areal coverage (Table 2) closely follows the pattern of population coverage.

By helicopter. Ninety-one percent of the Scottish population can access definitive critical care services within the 45 min by helicopter. The Island health boards – Western Isles, Orkney and Shetland – have no population or areal coverage by helicopter. Seven health boards (Ayrshire and Arran, Fife, Greater Glasgow and Clyde, Lothian, Lanarkshire and Tayside) have complete population coverage. The Borders have 55% population coverage, Dumfries and Galloway 50%, Grampian 71% and Highland 67% (Table 1). Areal coverage is complete in Fife, Greater Glasgow and Clyde and Lanarkshire only, but near-complete in Lothian (99%) and Forth Valley (96%). Areal coverage is much lower in the remaining board areas and as low as 34% in the Highlands.

Table 2 shows the population coverage by helicopter, by degree of rurality. Large urban areas have complete population coverage by helicopter, and other urban areas have near-complete coverage (98%). Accessible small towns have 85%, and accessible rural areas 86% population coverage. Very remote small towns and very remote rural areas have the lowest population coverage (24% and 30%, respectively). Areal coverage again broadly follows population coverage.

Access to intermediate critical care services

By road. Ninety-six percent of the Scottish population reside within a 45-min ambulance drive time of the nearest intermediate critical care service. This equates to 64% of the Scottish landmass.

Analysis by health board (Table 3) shows that population coverage by road ranges from 63% to 100%. Six health boards (Ayrshire and Arran, Fife, Forth Valley, Greater Glasgow and Clyde, Lanarkshire and Lothian) have complete population coverage. The health boards with lower population coverage are the Western Isles (63%), Shetland (64%), Orkney (77%) and Highland (77%). Areal coverage broadly follows population coverage, with lower coverage in the Highlands (40%), and on the Orkney (46%) and Shetland (41%) Islands and the Western Isles (38%).

The analysis by urban/rural classification category (Table 4) shows that 100% of the population residing in large urban areas, other urban areas and accessible small towns have access to intermediate critical care services by road within 45 min. Population coverage is also high in remote small towns (95%), accessible rural areas (98%) and remote rural areas (95%), but lower in very remote small towns (69%) and very remote rural areas (51%). Again, areal coverage broadly follows population coverage.

By helicopter. Ninety-five percent of the Scottish population can be retrieved and taken to the nearest intermediate critical care service within 45 min by helicopter, but there is considerable variation between health boards (Table 3). The Island health boards lie outwith of the range of the 45-min helicopter access time threshold, and thus have no population or areal coverage. The health boards serving the central belt all have complete population coverage. Highland (85%), Grampian (96%), the Borders (55%) and

Table 3. Accessibility by helicopter: Population and areal coverage, by health board.

Health board	Intermediate critical care facilities						Definitive critical care facilities			
	Area	Population	Area	Population		Area	Population			
Name	km ²	n	km ²	%	n	%	km ²	%	n	%
Ayrshire and Arran	3369	373,339	3369	100	373,339	100	3124	93	372,207	100
Borders	4732	113,615	2706	57	62,134	55	2706	57	62,134	55
Dumfries and Galloway	6426	151,302	3411	53	89,847	59	2921	45	76,170	50
Fife	1325	367,036	1325	100	367,036	100	1325	100	367,036	100
Forth Valley	2643	297,529	2643	100	297,529	100	2544	96	297,212	100
Greater Glasgow and Clyde	1104	1,143,934	1104	100	1,143,934	100	1104	100	1,143,934	100
Grampian	8736	568,800	6247	72	544,544	96	5058	58	406,419	71
Highland	32,593	320,067	17,621	54	273,090	85	11,075	34	215,894	67
Lanarkshire	2242	651,635	2242	100	651,635	100	2242	100	651,635	100
Lothian	1724	834,461	1714	99	834,299	100	1714	99	834,299	100
Orkney	990	21,349	0	0	0	0	0	0	0	0
Shetland	1467	23,154	0	0	0	0	0	0	0	0
Tayside	7527	409,481	7461	99	409,388	100	6796	90	408,807	100
Western Isles	3060	28,396	0	0	0	0	0	0	0	0

Table 4. Accessibility by helicopter: Population and areal coverage, by Scottish urban/rural classification category.

Scottish rural urban category	Intermediate critical care facilities						Definitive critical care facilities			
	Area	Population	Area	Population		Area	Population			
Name	km ²	n	km ²	%	n	%	km ²	%	n	%
Large urban areas	505	1,792,214	505	100	1,792,214	100	505	100	1,792,214	100
Other urban areas	691	1,780,740	689	100	1,745,686	98	689	100	1,745,686	98
Accessible small towns	188	451,419	182	97	436,087	97	177	94	381,533	85
Remote small towns	54	105,997	42	77	75,622	71	33	61	53,505	50
Very remote small towns	45	62,959	22	49	31,743	50	9	20	14,856	24
Accessible rural areas	18,558	748,324	15,677	84	671,349	90	14,498	78	645,322	86
Remote rural areas	17,828	184,698	14,342	80	150,435	81	12,493	70	136,513	74
Very remote rural areas	40,066	176,503	18,361	46	71,664	41	12,190	30	53,052	30

Dumfries and Galloway (59%) have lower degrees of population coverage. Areal coverage broadly follows this pattern, albeit with lower coverage in the Highlands (54%).

Analysis by urban/rural classification (Table 4) shows that large and other urban areas and accessible small towns have complete or near-complete population and areal coverage. Very remote small towns and very remote rural areas have the lowest population (50% and 41%, respectively) and areal (49% and 46%) coverage, respectively.

Sensitivity analysis: 60-min access time threshold

The results of the sensitivity analysis using a 60-min (rather than 45 min) access time threshold are shown

in Supplementary Tables 6–9. As expected, lengthening the access time threshold increases coverage. In terms of access to definitive critical care facilities, population coverage by road is complete or near-complete in all areas except the Highlands (61%), increased to 80% using helicopters. The Islands continue to have no coverage. All categories of the urban/rural classification have complete or near-complete access to definitive critical care facilities, by road and helicopter, except very remote small towns and very remote rural areas, which have 19% and 21% population coverage by road, respectively. Population coverage in these areas is increased to 47% using helicopters.

In terms of access to intermediate critical care facilities, a 60-min access time threshold marginally

improves health board population coverage by road. By helicopter, however, parts of the Orkney Islands become accessible. Lengthening the access time threshold improves population road coverage in very remote small towns and rural areas. In addition, helicopter use increases coverage in these areas to 90% and 73%, respectively.

Discussion

We have conducted a population-based evaluation of geographical access to critical care services in Scotland. We have established a methodology using freely accessible data to describe the proportion of the population that can access critical care services within 45 to 60 min, by road and by air.

There is an increasing interest in the concept of equity of access to healthcare resources.^{4,24} In countries with diverse geography, such as Scotland, ensuring equity is challenging, with evidence that there may be disparities in equity of access to critical care service. In another study from Scotland, Docherty et al. have shown that, after standardization for gender and socioeconomic status, there was evidence of regional variation in ICU admission rates for elderly patients. The authors concluded that their data indicated possible rationing, based on age, and geographic variation in access to care.²⁵ Quantifying the geographical access to critical care provides information on where these inequities lie, and how such disparities might be reduced.

We have shown that, residing within a 45-min drive to the nearest definitive critical care facility, and the aeromedical retrieval network providing definitive critical care access for 91% of the population, also within 45 min. An even greater proportion of the population have access to intermediate critical care facilities within this timeframe. In some areas, a greater proportion of the population can access critical care services within 45 min via road ambulance rather than air ambulance. This finding is the result of the location of the heliports, in Perth, Glasgow and Inverness. We have previously analysed these locations in relation to major trauma.¹²

Our data suggest that the current critical care network infrastructure can serve the majority of the population who develop a critical illness in a time-sensitive fashion. As might be expected, remote areas, and health boards serving these areas, have poorer access to critical care services, with certain isolated communities having poor access to level three critical care facilities, even via helicopter. We have shown that, of the mainland health boards, Grampian and Highland have relatively poor population access to critical care. Similarly, in terms of rurality, very remote small towns and very remote rural areas have poor access to definitive critical care facilities, but reasonable access to intermediate care. Remote small towns, accessible rural areas and

remote rural areas have surprisingly good access, even to definitive critical care. The number of people who live in remote areas is relatively small, but in a healthcare system which aims to provide equity of access, consideration should be given to addressing these inequities. This would, most likely, involve the enhancement of local facilities, as well as the existing aeromedical retrieval and transfer service, but requires further study.²⁶

This analysis has limitations. It is based exclusively on population distribution data, and the geographical distribution of patients who suffer critical illness may differ from that of the general population. The most frequent cause of critical illness outside of the home is trauma, but the organisation of trauma services differs from that of critical care, and has been extensively analysed.^{11,12} The use of an inbound-leg access time threshold can be questioned – arguably, the total time from notification of the ambulance service (regardless of whether by the patient, relatives, or a clinician) to arrival in hospital may be more important. However, most analyses have focused on inbound time only, at least in part because it is difficult to accurately model the outward leg of a journey – ambulances do not return to a ‘base location’ before attending the next call. In contrast, our model of helicopter tasking does incorporate both outbound and inbound legs, which reflects current practice, because most critically ill patients are seen by a local provider first. However, there are a number of factors, which we were not able to include in this model, including adverse weather conditions, night time flying and the time taken to transfer the patient from landing to the emergency department at the destination hospital. At present, the Scottish Ambulance Service does not have night-flying capability, which means that the realised access is less than half of the theoretical access.

However, this study also has several strengths. The most important are the population-based design, which provides a comprehensive picture of geographical accessibility, and the use of elliptical isochrones to monitor helicopter coverage. The use of smaller geographical units, such as health board regions, and the urban/rural classification, adds detail and granularity, and permits the identification of settings with poorer access. Furthermore, the analyses described here are technically straightforward, and can be conducted using freely and readily available data, making the techniques easily reproducible.

Conclusion

This study demonstrates the feasibility of profiling the accessibility of services using geographically referenced population distribution data. Overall, there is good population access to critical care services in Scotland, but there remain disparities, in identifiable areas. The impact of these disparities on

utilisation rates and clinical outcomes requires further study.

Declaration of conflicting interests

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