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Are differences in travel time or distance to healthcare for adults in global north countries associated with an impact on health outcomes? A systematic review

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ABSTRACT

Objectives: To investigate whether there is an association between differences in travel time/ travel distance to healthcare services and patient's health outcomes and assimilate the methodologies used to measure this.

Design: Systematic Review. We searched Medline, Embase, Web of Science, Transport database, HMIC, and EBM-Reviews for studies up to 24_11_2014. Studies were excluded that included children (including maternity), emergency medical travel, or countries classed as being in the global south.

Settings: A wide range of settings within primary and secondary care (these were not restricted in the search)

Results: 93 studies met the inclusion criteria. The results were mixed. 75% of the included studies identified evidence of a distance decay relationship, whereby patients living further away from healthcare facilities they needed to attend had worse health outcomes (e.g. survival rates, length of stay in hospital, nonattendance at follow up) than those that lived closer. 5 of the studies identified the reverse (a distance bias effect) whereby patients living at a greater distance had better health outcomes. The remaining 18 studies found no relationship. There was a large variation in the data available to the studies on the patient's geographical locations and the healthcare facilities attended and the methods used to calculate travel times and distances were not consistent across the studies.

Conclusions: This review observed that a relationship between travelling further and having worse health outcomes cannot be ruled out and should be considered as an input to the healthcare services location debate.

PROSPERO number: CRD42014015162

Strengths and Limitations of this research

- This systematic review has for the first time synthesized available evidence on the association between differences in travel time/distance to healthcare services and patient's health outcomes.
- It has identified a wealth of studies and generated evidence for wide range of disease groups and health outcomes, across multiple countries.
- There was great variation in study design, distances and travel time to access healthcare settings, and range of health outcomes; this precluded pooling of data for a meta-analysis.
- While the review findings are of undoubted value in broadening our understanding of the wider societal factors that influence health outcomes, their applicability may be limited to countries with similar healthcare systems.

INTRODUCTION

Countries such as the UK, USA and Canada have been implementing a policy of centralising the care of patients for certain specialised services. There is evidence that this process will have a positive impact on the health outcomes of those patients treated in these specialised centres ([1], [2]). However, there are also drawbacks to increasing the distance some patients travel to receive treatment. A number of authors have documented the "distance decay" relationship, which identifies that those that live closer to healthcare facilities have higher rates of utilisation after adjustment for need than those who live further away ([3 4]). Indeed as long ago as 1850 Jarvis proposed this distance decay effect by finding that fewer patients were admitted to a mental hospital in Massachusetts the further they lived from that hospital [5]. Whilst there is evidence of this "distance decay" relationship there is less evidence on how this translates into impacts on health outcomes. Having to travel further to access healthcare facilities and the impact this has on patients health requires further investigation.

A number of studies have determined transport accessibility levels to healthcare using Geographical Information Systems (GIS) techniques, by mapping car and public transport travel times and distances to healthcare facilities. However the link between transport accessibility to healthcare and the association of this with patients' health outcomes has not frequently been considered (in part due to a lack of linked health and transport data). The aim of this review is to bring together studies that have calculated the travel times and distances patients have travelled and explored whether there is an associated impact from this on health outcomes. Focusing on whether there is a relationship and what data and methods were used to explore this relationship.

METHODOLOGY

The review protocol was published in advance on the PROSPERO database (CRD42014015162). The study followed the PICOS search design [6]. The population were adults accessing healthcare in global north countries (including Northern America, Western Europe and Australia and New Zealand). The intervention and comparator were the distance and travel times to healthcare and the outcomes were any health outcomes. Study type was not restricted. We searched Web of Science, Medline, Embase, and Transport database, HMIC, and EBM Reviews for relevant papers in November 2014. The Medline search strategy is accessible in supplementary material 1. All titles and abstracts were screened by CK and 20% independently by CH. The key inclusion criteria were that the study quantified distance or travel time to healthcare AND identified whether there was an impact from this on health outcomes AND the assessment of travel time/ distance on the health outcome was the primary objective of the study.

The study excluded papers:

- including children (< 18 years olds and maternity)
- about patient opinions and views
- about one off emergency events or travel by different types of emergency vehicles including Myocardial Infarction and transfers between healthcare facilities
- on countries classed as Global South

The full papers of studies that met the inclusion criteria were reviewed by CK and CH. Data extraction and quality assessment was completed on all papers that met the full criteria. Reference lists of included papers were then reviewed to identify any additional studies. These were subjected to the same review process described above. The quality assessment of the studies was undertaken using a modified version of the CASP tool [7]. The areas of potential bias assessed are provided in table 1. The data was extracted and assessed for quality by two reviewers.

RESULTS

93 studies were included in the review and met the inclusion criteria. The study flow diagram is provided in Figure 1, which shows that over 11,000 abstracts were initially reviewed. 75% of the included studies had identified a distance decay association – as distances or travel times increased this led to worse health outcomes (see table 2). 5 studies reported the opposite - health outcomes were better the further the

patient lived from the healthcare facility (see table 3) and 18 identified no relationship (see table 4). Studies covering a wide range of diseases, interventions and health outcomes where identified. The results of the quality assessment are summarised in table 1. No studies were excluded on the basis of this assessment.

Table 1 Quality Assessment of Studies n (%)

	Yes	No	Unclear/Partial
Did the study address a clearly focused question?	93 (100%)	0	0
Was the study population recruited in an acceptable way?	90 (96.8%)	0	3 (3.2%)
Did it include all the population or describe the population not included?	82 (88%)	7 (7.5%)	4 (4.3%)
Was the method used to calculate the distance/ travel time reported accurately?	72 (77.4%)	21 (22.3%)	0
Was the health outcome accurately measured to minimise bias?	93 (100%)	0	0
Have important confounding factors been taken account of in the design or analysis?	77 (82.8%)	16 (17.2%)	0
Is the funding source external to the organisation?	63 (67.7%)	8 (8.6%)	22 (23.7%)
Was the research peer reviewed?	86 (92.5%)	0	7 (7.5%)

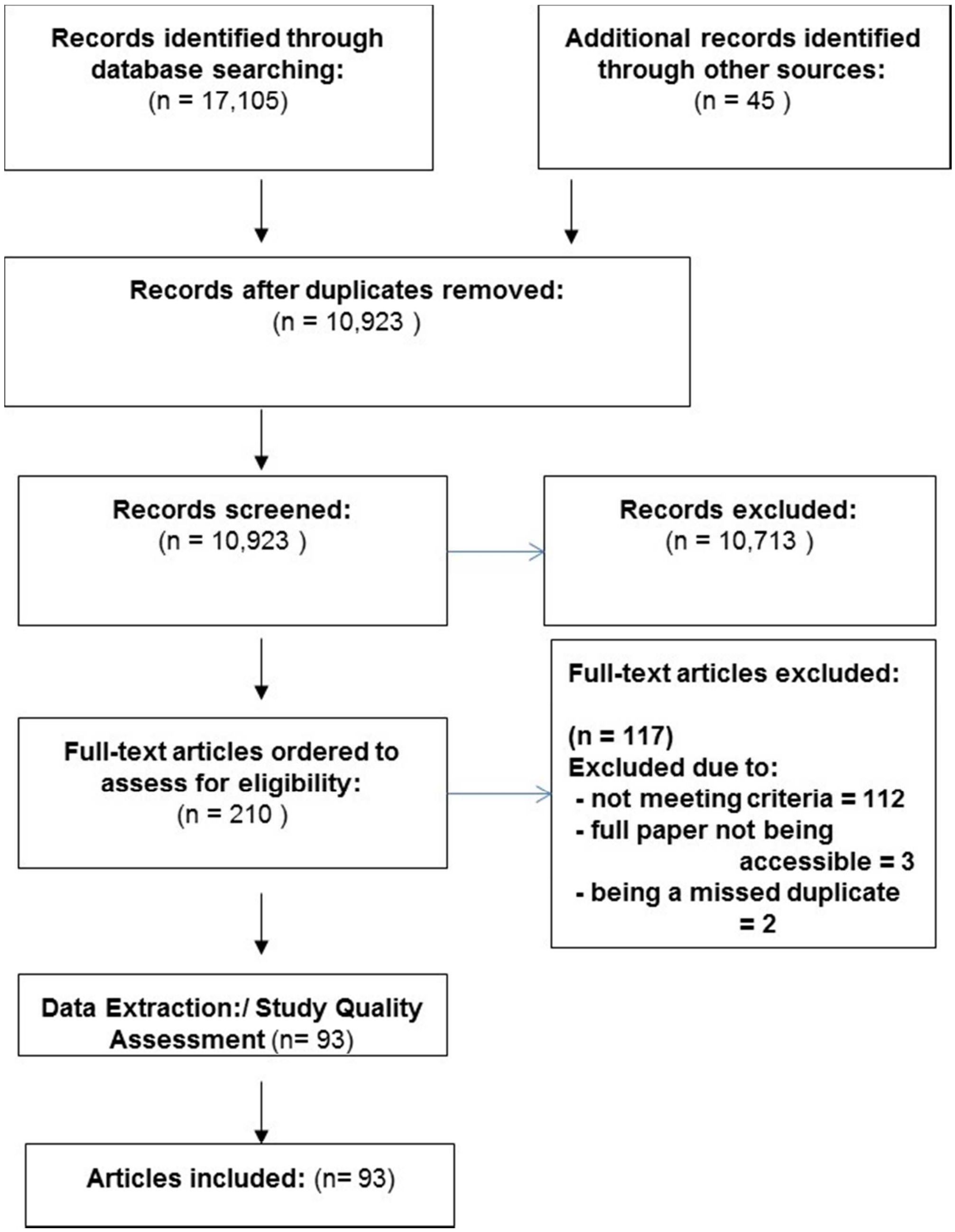

Figure 1: Flow Diagram of papers

Table 2: Included studies that identified a distance bias relationship

Author Country	Disease / Procedure	Source, Years & Sample size	Health Outcome	Distance/ travel time measurement	Origin and Destination	Summary of key results
Punglia, et al. [8] USA	Breast Cancer	The linked Surveillance, Epidemiology and End Results- Medicare (SEER) database. 1991 - 1999. Sample = 19,787	Receiving Radiation Treatment after a Mastectomy	Straight Line Distance. Distance was treated as a continuous and categorical variable. Using categories of <25, 25-50, 50-75 and 75+ miles. 5 patients living more than 900 miles away were excluded, as were patients in Hawaii. The median distance was 4.83 miles.	Patients Residence TO The nearest radiation treatment facility.	The study found that increasing distance to the nearest radiation treatment facility was associated with a decreased likelihood of receiving radiation treatment therapy. When modelled as a categorical variable - each 25 miles in additional travel was associated with declining odds of receiving radiation. The effect of distance showed as being stronger where patients were >75 years and those travelling 75+ miles compared to <25 miles.
Nattinger, et al. [9] USA	Breast Cancer	National Cancer Institute - Surveillance, Epidemiology and End Results (SEER) Registry. 1991 - 1992. Sample = 17,729	Receiving Breast conserving surgery (BCS) & receiving BCS with radiotherapy.	Straight-line Distance. Distance was treated as a categorical variable - using the groups of < 5miles, 5 to <10, 10 to < 15, 15 to < 20, 20 to <30, 30 to <40, ≥ 40 miles for receipt of BCS vs mastectomy and the groups of 0 to <10, 10 to <20, 20 to <30, 30 to <40 and ≥ 40 miles for receipt of radiotherapy among BCS patients.	Census tract of the residence of the patient TO The centroid of the zip code of the nearest hospital with a radiotherapy facility.	The study found a statistically significant decline in the likelihood of patients undergoing breast conserving surgery living 15 or more miles from a hospital with radiotherapy facilities when compared to those living < 5miles. They also found a statistically significant result for those patients living ≥ 40 miles having an reduced rate of radiotherapy following Breast conserving surgery.
Engelman, et al. [10] USA	Breast Cancer	The Health Care Financing Administration enrolment database to identify each fee for service Medicare eligible women in Kansas. - Medicare Claims data. 1997 - 1998	Mammogram attendance	Straight-line Distance. The study categorized distance as a continuous variable in the logistic regression model.	Residence zip codes TO The zip codes of the nearest permanent & mobile mammography sites.	The study showed that increasing distance from a permanent mammogram facility was significantly associated with decreased mammogram rates. After controlling for age, race and education this relationship was still significant. OR = 0.97 for each 5 mile increment.

		Sample = 117,901				
Panagopoulou, et al. [11] GREECE	Breast Cancer	Hellenic Cooperative Oncology Group (clinical trials in 6 Greek cities) 1997 - 2005 Sample = 2,789 (women)	Survival	Road distance and travel time. Distance was grouped into < 300km and ≥ 300km. Travel time was grouped into < 4 hours and 4+ hours. Additional tests using the following distance categories: <50, 50 - 149, 150 - 249, 250 - 349, 350+km.	Residential address (98.7% of the sample using residential address, or the city centre of the city of residence, for the remaining 1.3% the weighted mean of available distances to each destination hospital) TO The treating hospital	The study found that travelling a distance >300km and travel time of 4 + hours were significantly associated with worse survival outcomes (HR = 1.37 & 1.34) base <300km and <4h respectively.
Maheswaran, et al. [12] UK	Breast Cancer	Anonymised data April 1998 - March 2001 Sample = 34,868	Breast Screening Uptake	Road distance. Distance was treated as a categorical variable and a continuous variable. Distances were grouped into 2 km bands. <2km, 2 to <4, 4 to <6, 6 to<8 and ≥8	Residential Postcode TO The screening location that they were invited to attend.	The study found that when analysed as a continuous variable there was a small but significant decrease in uptake of breast cancer screening with increasing distance - adjusted odds ratio of 0.87 (95% CI -0.79 - 0.95) for a 10km increase in distance. The strongest effect on breast screening uptake was deprivation.
Wang, et al. [13] USA	Breast Cancer	Illinois Cancer Registry 1998 - 2000 Sample = 30,511 (9,077 were classed as late stage)	Late stage diagnosis	Road distance and travel time. Travel times were calculated using the ArcInfo network analysis module – Minimum road distance when taking account of travel speed.	Population weight centroid of zip codes TO The closest mammography facility & the closest GP.	The study found that travel time to mammography services had no statistically significant association with late stage risk. The study did find that as travel time to the nearest GP increased patients were more likely to have a later stage diagnosis.
Jones, et al. [14] UK	Breast colorectal, lung, ovarian and prostate cancer	Northern and Yorkshire Cancer Registry and Information Service (NYCRIS) 1994 - 2002 Sample = 117,097	Survival (whether patients were alive or dead on 31st March 2005) and late stage diagnosis	Travel times. Calculated using average car travel speeds by road class on the road network. Travel time was treated as a continuous variable. The study also determined: - whether patients were within 800m of an hourly bus service for rural patients. Straight-line distance to the nearest cancer centre, car journey to the closest railway station, travel	Patients home TO The GP, Hospital of first referral and closest cancer centre	The study found that late stage diagnosis was associated with increasing travel time to the GP for breast and colorectal cancer and risk of death was associated with increased ravel time to the GP for prostate cancer. The study identified residential deprivation was significantly related to survival.

				time to the GP and first referral hospital.		
Haynes, et al. [15] New Zealand	Cancer (prostate, colorectal, breast, lung, melanoma)	New Zealand Ministry of Health 1994 - 2006 Sample = 1,383	Late diagnosis and likelihood of death	Travel Time. Travel time was treated as a categorical variable and split into 4 categories (Low, medium, High, Highest) low - lowest quartile, medium (quartile 2 and 3) High records between 75% and 95 percentiles and highest - highest 5% of records. This grouping was used to account for the skewed travel times.	Population weighted centroid of the 2001 census area units (CAU represent approx. 2300 people) TO The nearest cancer centre and nearest GP	The study had mixed results. After controlling for the extent of the disease, poor survival was associated with longer travel times to the GP for prostate cancer and longer travel times to the nearest cancer centre for colorectal, breast and prostate cancers, but not lung cancer or melanoma The study found that the disease tended to be less advanced in patients who lived further from the cancer centres and living further from a GP practice was not associated with a later stage diagnosis.
Cramb, et al. [16] AUSTRALIA	Breast Cancer and colorectal cancer	Queensland Cancer Registry. 1996 - 2007 Sample = 26,390 Males = 14,690 and Females = 11,700	Survival and premature deaths	Travel Time. Shortest travelling time by road. Travel time was grouped into 3 categories based on practical considerations. < 2hours, 2 - 6 hours and >6 hours	Centroid of the patients statistical local area TO The closest radiation facility	The study concluded that the proportion of premature deaths was higher for those living >2 hours from a treatment facility for breast cancer. Colorectal patients living > 6 hours from a treatment facility had poorer outcomes than those in the 2- 6 hour category, but this was not statistically significant.
Jones, et al. [17] UK	Cancer (Colorectal, ovary, breast, prostate)	Northern and Yorkshire Cancer Registry Information Service. 1994 - 2002. Sample = 3,536	Whether or not the diagnosis was made at death. (Diagnosis date = death date)	Road Distance and Travel time Estimated using average travel speeds over the road network. The study also calculated straight-line distance and assessed whether patients lived within 800m walking distance of an hourly weekday bus service & whether there was a local community transport scheme. Travel time to hospital was modelled as a categorical variable using quartiles.	Home Postcode TO The nearest healthcare provider postcode/ Nearest GP	The study found that the highest odds of being diagnosed at death were for those living in the least accessible quartile of travel time for the hospital, but this association was only statistically significant for colorectal and ovary cancer. The study found that living in the least accessible travel time quartile to the GP had the highest odds of being diagnosed at death, but was not statistically significance. Breast and prostate cancer patients living closer to a frequent bus service were significantly less likely to be diagnosed at death.

Schroen, et al. [18] USA	Breast Cancer	Virginia Cancer Registry. Patients diagnosed 1996 - 2000. Sample = 20,094	Mastectomy rates VS Breast conservation and radiation therapy	Straight-line Distance. Distance was modelled as a categorical variable < 10 miles, 10 - 25, > 25 - 50 and > 50 miles (range 0 - 84miles)	Residential zip code TO The nearest radiation therapy facility.	The study found a higher rate of mastectomy the further distance the patient lived from the nearest radiation therapy facility (after controlling for tumour size, year of diagnosis and age).
Athas, et al. [19] USA	Breast Cancer	New Mexico Tumour Registry & The National Cancer Institute's surveillance Epidemiology and End Results. Patient Diagnosed 1994 – 1995 Sample = 1,122	Receipt of radiotherapy following breast conserving surgery	Straight-Line Distance. The distance was split into the following categories: <10 miles, 10.0-24.9, 25.0-49.9, 50.0-74.9, 75.0-99.9, ≥100 miles.	Residential street address (70% of cases) and centroid of residential zip codes (30%). TO The nearest radiation treatment facility.	The study found that by controlling for age the likelihood of receiving radiotherapy following breast conserving surgery decreased significantly with increasing travel distance to the nearest facility. This was significant for distances >74.9miles compared to a base of <10miles.
Meden, et al. [20] USA	Breast Cancer	Medical Records. 1999 – 2000 Sample = 66	Difference in treatment technique – Modified Radical Mastectomy vs Breast Conserving Therapy	Distance. Unclear method. Likely to be straight-line. Distance was treated as a categorical variable. Distances were split into <45 miles and ≥45miles. Average distance was 61.6 miles (range 0 – 138 miles)	Residential Address TO The nearest radiation oncologist facility.	The study found that access to Breast conserving surgery declined as travel distance increased. Patients living further away were more likely to have had a mastectomy.
Celaya, et al. [21] USA	Breast Cancer	New Hampshire State Cancer Registry. 1998 - 2001. Sample = 2,861	Type of treatment received - either breast conserving surgery with radiography or Mastectomy	Straight-line Distance. Distances were treated as categorical variable using the groups <20 miles, 20 to <40, 40 to < 60, ≥60 miles. The mean distance was 15.1 miles (range 0.1–89.9).	Residential Address geocoded (80%) or zip code centroid (20%) TO The nearest radiation treatment facility.	The study found that women were less likely to have breast conserving surgery with increasing distance from the nearest facility. Women were less likely to have radiation therapy the further away they lived - if they had previously undergone breast conserving surgery.

Huang, et al. [22] USA	Breast Cancer	Kentucky Cancer Registry. 1999 - 2003 Sample = 12,322	Diagnosis Stage	Road Distance. Distance was treated as a categorical variable using the groups - <5 miles, 5 - 9, 10 - 14 and ≥15 miles	Patients Residence - 78% were geocoded based on street address. 15% using the centroid of the 5 digit zip code and 7% using the 5 digit zip code + 2 or + 4 digits TO the nearest mammogram centre	The study found that patients diagnosed with advanced stage diagnosis had longer average travel distances than early stage diagnosis. After controlling for age, race, insurance and education the odds of advanced diagnosis were significantly greater for women living ≥15 miles compared to those living <5 miles.
Jethwa, et al. [23] USA	Breast Cancer	Hospital Records. 2007 Sample = 260 (women were excluded if they were non-white or had a previous cancer diagnosis)	Stage of breast cancer at diagnosis, survival	Distance. (Unknown calculation). Distance was treated as a categorical variable using the following groups: < 15 miles, 15 - 44 miles, 45 - 59 miles, and ≥60 miles.	Patients home TO The treating hospital	The study found that the further the distance the more likely women were to be diagnosed at a later stage and the more likely women were to have a mastectomy. The study found no association between travel distance, age at diagnosis, receipt of radiotherapy, or 5-year survival.
Onitilo, et al. [24] USA	Breast Cancer - Mammography Screening	Local Cancer Registry. 2002 - 2008. Sample = 1,421	Stage at diagnosis	Road distance and travel time. Road Distance and Travel time calculated using ESRI ArcGIS. Distances were treated as continuous & categorical variables Using the categories of 0 - 5 mins, 5 - 15 mins, 15 - 30 mins, 30 - 60 mins, ≥ 60 mins.	Street address for the patients (where available) /centroid of patients zip code where not) TO The nearest mammogram facility and also the actual facility attended.	The study found that women who missed none of their 5 annual mammograms lived a median of 15 minutes from the nearest facility, whilst those who missed 5 /5 lived a median time of 27 minutes. The study found that patients living >30 miles to the closest facility were less likely to be screened for breast cancer in the winter months.
Crawford et al. [25] UK	Lung Cancer	Northern and Yorkshire Cancer Registry and Information Service. 1994 - 2002 Sample = 34,923	Diagnosis and form of treatment	Travel time. Calculated using ArcGIS 9.2 using average car speeds along the shortest route. Travel time was treated as a categorical variable - dividing the patients into equal quartiles. Patients were then	Patients residence TO The closest hospital providing diagnostic access.	The study found that patients living in the most deprived areas were least likely to receive histological diagnosis, active treatment and thoracic surgery. They found that travel time amplified this effect – patients in the most distant & most deprived group had the worst outcomes.

				put into 1/ 16 groups that combined 4 quartiles of travel time and 4 quartiles of deprivation.		
Brewer, et al. [26] NEW ZEALAND	Cervical Cancer	New Zealand Cancer Registry. 1994 - 2005 Sample = 1,383	Cancer screening, stage at diagnosis and mortality	Travel time and distance. The distances and travel times were treated as a categorical variable using the following method of grouping - low - the lowest quartile, Medium - quartiles 2 and 3, High - records between the 75th and 95th percentiles and Highest - the highest 5% of records.	The 2001 census area unit for the patient (population weighted centroid) TO The nearest GP and nearest Cancer Centre	The study found that increased travel time/ distance was only weakly associated with cervical cancer screening, stage at diagnosis and mortality.
Burmeister, et al. [27] AUSTRALIA	Lung Cancer	Queensland Cancer Registry. 2000 - 2004 Sample = 1,535	Delay in receiving radiation therapy Survival	Road Distance. (no info on GIS methods used) Distance was treated as a categorical variable using the groups of < 50km (where it was assumed that patients could travel on a daily basis from home) 50 - 200km (where it was assumed patients would go home for weekends only) and > 200km (where it was assumed that patients would need to spend the duration of their treatment at the hospital).	Patient residence (postcode) TO The nearest public radiation treatment facility.	The study found that waiting times for radiation therapy among lung cancer patients in Queensland was not associated with distance from home to the nearest public radiation treatment facility. The study did find that those living > 200km away had slightly worse survival than those who lived < 50km.
Bristow, et al. [28] USA	Ovarian Cancer	Californian Cancer Registry 1996 - 2006 Sample = 11,770	Treatment Adherence	Distances. (Does not say what method used) calculated using ArcMAP Distance was treated as a categorical variable and split into quintiles from < 5km up to > 80km.	Patients Residence TO The treating hospital and the closest high volume hospital.	The study found that living > 80km (compared to < 9km) from a high volume hospital was associated with an increased risk of non-adherence to care plans (OR = 1.88, Confidence interval, 1.61 - 2.10). The study found that distance to a high volume hospital and distance to receive treatment could be used to predict whether patients would meet the guidelines for car for advanced stage ovarian cancer.

Tracey, et al. [29] AUSTRALIA	Epithelial Ovarian Cancer	New South Wales Cancer Registry. 2000 - 2008. Sample = 3411	Survival	Straight-Line Distance. Distance was treated as a continuous variable and categorical variable for which it was grouped into equal quartiles - 0 - 5km 5.1-9.0km, 9.1-27.0, 27.1 - 187.0, 187.1+	Patients home TO The closest gynaecological oncology Hospital	The study concluded that there was an increasing trend in the unadjusted hazard of death model with increase in distance to the closest public gynaecological Oncology hospital. The study reported that whilst they had used the closest hospital in their calculations only 37% of their sample had used their closest hospital.
Holmes, et al. [30] USA	Prostate Cancer	Physician workforce study in North Carolina & North Carolina Central Cancer Registry on patients diagnosed with incident cancer linked to Medicare claims. 2004 - 2005 Sample = 2,251	Delayed Diagnosis	Straight-line distance. Distance was treated as a categorical variable and used 3 groups of: 0 - 10 miles, 11 - 20miles and > 20 miles.	Zip code centroid of patient residence TO The nearest urologist	The study found that increasing distance to an urologist was significantly associated with higher risk of prostate cancer at diagnosis, which was higher for black patients.
Kim, et al. [31] UK	Colorectal cancer	South and West Cancer Intelligence unit. 1991 - 1995 Sample = 4,962	Survival	Straight-line distance. Distance was treated as a categorical variable using the following groups - ≤10 km, > 10 to ≤ 20 km, > 20 to ≤ 30 km and > 30km.	Home postcode TO The treating Hospital	The study found that those travelling ≥ 30km from the treating hospital had significantly poorer survival, but that those living between 20 - 30 km appeared to be least at risk. Implying a U shape in terms of risk.
Dupont-Lucas, et al. [32] FRANCE	Colorectal Cancer	Clinical trials in Calvados Normandy and Cote-d'Or Burgundy - testing the diagnostic properties of two types of faecal occult blood test. June 2004 - December 2006 Sample = 4,131	Colonoscopy uptake	Road distances. Calculated using mapinfo 9.1 combined with CHRONOMAP 2.1 based on the MultiNet Map database (Tele Atlas). Distances were grouped into quartiles: 0 - 5.5km, 5.5 - 13.8, 13.8 - 22.1 & 22.1 - 52.3km.	Patient Home Address TO The nearest Gastroenterologist / or regional capital /or clinical trial centre	The study found that distance to the regional capital and distance to the clinical trial centre were independently associated with colonoscopy uptake. Distance to the nearest gastroenterologist was not found to be significant.

Fournel, et al. [33] FRANCE	Colorectal Cancer	Burgundy Registry. 1990 - 1999. Sample = 6220 colorectal adenoma patients and 2,387 colorectal cancer patients.	Colorectal adenoma detection	Distance. (method not reported) Distances were included as a categorical variable using groupings of <5km, 5 - 15km and >15km.	Place of Residence TO The GP, hepatogastroenterologist (HGE), and physician (not clear whether these were the nearest)	The study found that incidences of colorectal cancer were not significantly associated with distance to the GP, HGE, or the physician. The study did find a significant interaction between place of residence and the distance to the GP and place of residence and the HGE. The impact of the distance to the physicians was only significant for patients living in rural areas.
Dejardin, et al. [34] FRANCE & ENGLAND	Colorectal cancer	3 Cancer registries (Calvados, Cote d'Or and Saone et Loire) and 1 cancer registry in England (Northern and Yorkshire). 1997 - 2004 Sample = 40,613	Survival	Travel time. Using ArcGIS in England and Mapinfo in France. Road map databases using legal speed limits by road class. Travel time was treated as a categorical variable using the 5 groups of 0 - 5 mins, 6 - 20 mins, 21 - 40mins , 41 - 90 mins and ≥ 91mins for travel times to the nearest cancer centre & nearest radiotherapy unit and 0 - 5, 6 - 10, 11-15, 16 - 40 and ≥41mins for travel to the nearest hospital.	Residential location of patients at the time of diagnosis TO The nearest cancer centre, radiotherapy centre and hospital.	The study identified in the unadjusted analysis that travel times were significantly associated with survival, as patients living further from healthcare resources had a better chance of survival than those living closer. When including material deprivation in the model this effect was removed.
Anderson, et al. [35] USA	Colorectal Cancer	A set of cross sectional telephone survey of the population > 18 years in the USA. Taken from the Utah Behaviour Risk Factor Surveillance System. 2010 Sample = 2,844	Adherence to risk appropriate screening guidelines	Travel Time. Shortest Path. The study calculated 1 mile grid cells for the state of Utah and for each grid cell populated with individuals aged 50 or older they calculated the actual travel time to the nearest colonoscopy provider. This was then used to calculate a population weighted median travel time by zip code. Travel times was treated as a categorical variable and grouped into 3 categories: <10 minutes, 10 - 20 minutes & >20 minutes.	1 mile grid reference for the patient TO The nearest colonoscopy provider.	The study found that residents living > 20 mins from the nearest colonoscopy provider were significantly less likely to be up-to-date with risk appropriate screening than those living < 10 mins from the nearest provider.

Campbell, et al. [36] UK	Colorectal and Lung Cancer	Scottish Cancer Registry 1995 - 1996 Sample = 1,398	Presence of disseminated disease at diagnosis & emergency presentation or surgery.	Straight-line Distance. Distance was treated as a categorical variable using the groups of 0 - 5km, 6 - 37km, 38 - 57km and ≥58km. These were pre-defined cut off points.	Patients Residence - (Census output area centroids) TO The nearest cancer centre.	The study identified that increasing distance from the nearest cancer centre was associated with a higher chance of disseminated disease at diagnosis, but not for emergency emissions or patients requiring emergency surgery.
Baade, et al. [37] AUSTRALIA	Rectal Cancer	Queensland Cancer Registry (QCR) 1996 - 2007 Sample = 6,848	Cause specific survival	Road distance & travel times. The distances were treated as a categorical variable using the following groups: < 50km, 50 - 99km, 100 - 199, 200 – 399 and ≥400km. The travel times were treated as a categorical variable using the categories of 0 -1hours, 2-4, 4-6, ≥ 6 hours	Patients Residence TO The nearest radiotherapy facility	The study found that after adjusting for age, sex and stage at diagnosis, patients who lived 100 - 199km, 200-399km and 400km or more from a radiotherapy facility were 16%, 30% and 25% respectively more likely to die from cancer than patients living within 50km of such a facility. For every 100km increase in distance there was on average a 6% increase in risk of mortality. Similar results were found when travel time was used in the calculations, where patients living greater than 6 hours away were 22% more likely to die from cancer than those living 0- 1 hours away.
Lavergne, et al. [38] CANADA	Palliative Radiotherapy (PRT)- Cancer	Oncology Patient Information System (Nova Scotia) 2000-2005 Sample = 13,494	PRT Treatment & Consultation	Travel Time. Using GIS and average vehicle speeds by road type. Distance was treated as a categorical variable using 4 categories: 0 - <30 mins, 30 - < 60 mins, 60 - < 120 mins and 120 - 214mins.	Residents postcode at death TO The closest treatment centre	The study found that Palliative radiotherapy use declined with increasing travel time and community deprivation.
Abou-Nassar, et al. [39] USA	Stem Cell Transplant	Clinical Operations and Research Information Systems database at DF/BWCC. 1996 - 2009. Sample = 1912 (meeting the criteria of living < 6 hours to the treatment centre).	Overall Survival	Travel Time. Calculated using driving distance and average driving time along the street network Travel time was treated as a categorical variable using 3 groups' ≤40, 41 - 159, ≥160 mins and also a continuous variable. The range of distances was 2 - 358 mins.	Primary residence TO The transplant Centre	The study found that longer drive times to the transplant centres was associated with worse overall survival in patients alive and disease free after 1 year - This was only true using travel time as a continuous variable. They suggest this may be in part related to the lower number of visits in patients living further away after the transplant.

Kerschbaumer, et al. [40] AUSTRIA	Glioblastoma Multiforme (GBM) - malignant brain tumor	Medical Records 1990 - 2009 Sample = 208	Survival (Months)	Shortest driving distance. Distance was treated as a continuous variable. Average distance was 75km (range 1 - 870km)	Distance from patients homes TO The neuro oncological centre	The study found that distance to the neuro oncological centre had a significant effect on overall survival. Patients were less likely to be treated with chemotherapy following surgery the further the distance away they lived. The study found that when a new treatment was introduced that could be administered locally this removed this effect.
Campbell, et al. [41] UK	Cancer (Lung, Colorectal, Breast, Stomach, Prostate, Ovary)	Scottish Cancer Registry 1991 - 1995 Sample = 63,976	One Year Survival	Straight-line distance. Distance was treated as a categorical variable using the groups ≤ 5km, 6 - 13km, 14 - 23km, 24-37km and ≥38km.	Residential postcode TO The nearest cancer centre	The study found that increasing distance from the nearest cancer centre was associated with a reduced chance of diagnosis before death for stomach, breast and colorectal cancer and poorer survival after diagnosis for prostate and lung cancer.
Jones, et al. [42] UK	Breast, Colon, Rectum, Lung, Ovary and Prostate Cancer	Northern and Yorkshire Cancer Registry (NYCRIS) 1994 - 2002 Sample = 117,097	Patients receiving surgery, chemotherapy or radiotherapy	Travel Time. Travel time was modelled as a categorical variable and divided into quartiles.	Patients postcodes TO The nearest hospitals providing treatment.	The study identified an inverse relationship between travel time and treatment take up. Patients were less likely to receive radiotherapy the further they lived from the hospital. Lung cancer patients were less likely to receive surgery & Lung and rectal patients were less likely to receive chemotherapy.
Chou, et al. [43] USA	Coronary artery bypass graft (CABG)	Pennsylvania HealthCare Cost Containment Council 1995 - 2005 Sample = 102,858	In hospital mortality and readmission	Straight-line distance. Distance as a continuous variable. Average distance 14.9 miles.	Centroid of the patient's residential zip code. TO The admitting hospital	The study found that high risk Coronary Artery bypass graft patients living further from the admitting hospital had increased in-hospital mortality.
Singh, et al. [44] CANADA	Cardiac	Brunswick Cardiac Centre. 2004 - 2011. Sample = 3,897	30 day rates of adverse events following non-emergency cardiac surgery	Driving distance. Distance was treated as a categorical variable using the following groupings: 0-50km, 50 - 100km, 100 - 150km, 150 - 200km, 200 - 250km and >250km.	Patients Home TO The Cardiac Surgery Centre	The study found that increased distance from the cardiac surgery centre was independently associated with a greater likelihood of experiencing an adverse event at 30 days.
Thompson, et al. [45]	Kidney Disease	United States Renal Data System. Jan 1995 – 2007 Sample = 726,347	Mortality	Shortest Driving Distance. Distance was treated as a categorical variable. Using 5 categories: 0-10 miles, 11-15, 26-45, 46-100 and >100miles.	Patient 5 digit zip code (at time of first renal replacement, dialysis or transplant) TO	The study found that distance, but not living in a rural area was associated with increased mortality. The adjusted model identified a statistically significant hazard ratio between the reference case (0-10milles) and the 11-25 miles and >100miles

		(the study excluded patients with missing or invalid postcodes)		The categories correspond to the 0 – 75th , 75-95th, 95th -99th, 99th-99.9th and >99.9th percentiles.	The closest Haemodialysis Centre	categories, but not for other distance categories.
Bello, et al. [46] CANADA	Diabetes & Chronic Kidney Disease (jointly)	Alberta Kidney Disease Network & Provincial Health Ministry 2005 - 2009 Sample = 31,377	All-cause mortality, all cause hospitalisation, renal outcomes, ESRD initiation, progression to Egfr< 10mL/min/1.73m)	Road Distance. Distances were treated as a categorical variable. Using the following 6 categories 0-50, 50.1 - 100, 100.1 - 200 and >200km	Patients residential 6 digit postal code TO The nearest nephrologist	The study found that when using a base of <50km, patients living >50km were less likely to visit a nephrologist, less likely to have follow up measurements of A1c and urinary albumin within a year. Plus have a higher change of all cause hospitalisation and all-cause mortality.
Judge, et al. [47] UK	Renal Replacement Therapy (RRT) - Kidney	UK Renal Registry (UKRR) 2007 Incident population = 4607 Prevalent population = 36,775	Renal Replacement Therapy Incidence and Prevalence	Travel time. Average speeds were assigned to roads and GIS transportation software Base Trans CAD used to estimate the minimum travel time. Travel time was treated as a continuous and categorical variable split into 4 groups: < 15mins, 15 - 29mins , 29 – 45, & 45+ mins	Centroid of the CAS Ward (average 2670 people in each ward) TO The nearest Dialysis Unit	The study found that patients living >45 min travel time from the nearest dialysis unit were 20% less likely to commence or receive renal replacement therapy than those living < 15 min.
Moist, et al. [48] USA	Kidney Dialysis	Dialysis Outcomes and Practice Patterns Study (DOPPS) - questionnaire 1996 - 2001 (DOPPS 1) 2002 - 2004 (DOPPS 2) Sample = 20,994 (from 7 countries, France, Germany, Italy, Japan, Spain, UK and USA)	HRQOL (Health Related Quality of Life), Mortality, Adherence, withdrawal, hospitalisation and transplantation	Travel Time. The study was based on a survey which asked the question - How long does it take you to get to your dialysis unit or centre (1 way)? Respondents could answer ≤15mins, 16 - 30, 31 - 60 and >60mins. They were also asked how they usually travelled to the dialysis unit. .	Patient home TO The dialysis centre attended	The study found that longer travel times were associated with a greater adjusted relative risk of mortality. Health related quality of life scores were lower for those with longer travel times when compared with travelling < 15mins.

Cho, et al. [49] AUSTRALIA	Peritonitis (Kidney)	ANZDATA Registry 2003 - 2008 Sample = 6,610	A range including - Peritonitis Free - Survival, first peritonitis episode, staphylococcus aureus peritonitis.	Road Distance. Using Google maps. Distance was treated as a categorical variable using the groupings - < 100km and ≥100km. The cut off was decided a priori as this is the minimum distance states provide patient assisted transport subsidy schemes to facilitate improved access.	Patients Residence TO The nearest peritoneal dialysis unit.	The study found that living ≥100 km away from the nearest peritoneal dialysis unit was not significantly associated with time to first peritonitis episode. The study did find a relationship between living ≥ 100km away from the nearest unit and increased risk of Staphylococcus aureus peritonitis.
Bello, et al. [50] CANADA	Patients with proteinuria (Kidney Damage)	Alberta Health and Wellness, Alberta Blue Cross, the Northern and Southern Alberta Renal Program and the provincial laboratories of Alberta. 2002 - 2009 Sample = 1,359,330	A range of health outcomes. ACEI/ARB use in ≥ 65 year olds, Statin use in ≥ 65 year olds, Timely Referral, All cause mortality, myocardial infarction, stroke, heart failure, doubling of SCr (Serum creatinine ratio), ESRD (end stage renal disease) and hospitalisations	Shortest driving distance. Distances were treated as a categorical variable using the groups : 0-50, 501 - 100, 100.1 - 200 and >200km.	Patients 6 digit home postal code TO The nearest nephrologist.	The study found a statistically significantly higher incidence of stroke and hospitalisations in those travelling a greater distance, but no association for the other outcome measures
Thompson, et al. [51] USA	Kidney	United States Renal Data System 2001 - 2010 Sample = 1,784	Quality of Care Indicators (90 days following haemodialysis therapy and at 1 year)	Shortest Driving Distance. Distance was treated as a categorical variable. Using the following categories: ≤50km, 50.1 - 150km, 150.1 - 300, >300km.	Patient 5 digit zip code TO The closest nephrologist.	The study found that patients were less likely the further they lived from a haemodialysis centre to have seen a Nephrologist 90 days prior to starting haemodialysis therapy, and were more likely to have a sub optimal levels of phosphate control.

Miller, et al. [52] CANADA	Chronic Kidney Disease	Canadian Organ Replacement Registry (CORR) 2000 - 2009 Sample = 26,449	Incident Central Venous Catheter (CVC) use	Straight-line Distance. Distances were divided into 3 groups <5km, 5 - 20km and >20km	Patients postal code of their primary residence at dialysis initiation TO The nearest dialysis centre	The study found that increasing residential distance was associated with increased use of central venous catheters in incident dialysis patients.
Tonelli, et al. [53] CANADA	Kidney Failure	Canadian Organ Replacement registry 1990 - 2000 Sample = 26,775	Mortality	Shortest distance by road. Calculated using postal data converted using www.melissadata.com and entered into ArcGIS. Distance was treated as a categorical variable using the groups of: <50km, 50.1 - 150km, 150.1 - 300 and >300km	Patients Residence (6 digit postal code) TO The practice location of their nephrologist.	The study found that remote dwelling Canadians with kidney failure were significantly more likely to start renal replacement on Peritoneal Dialysis (PD) and switch to PD if their initial dialytic option was haemodialysis. The adjusted rates of death and the adjusted hazard ratios were significantly higher in those living ≥50km from the nephrologist compared to those < 50 km.
Tonelli, et al. [54] Canada	Kidney (Haemodialysis)	Canadian Organ Replacement Register 1990 - 2000 (when the sample started dialysis) Sample = 18,722 (random sample of 75% of the patient population)	Mortality (from all causes) Then split by cause - infectious or cardiovascular	Shortest distance by road. Calculated using ArcGIS 9.1. Distance was treated as a categorical variable using the following groups - 0-50km, 50.1-150km, 150.1-300km, >300km	Patients Residence TO The practice location of the attending nephrologist.	The study found that mortality associated with haemodialysis was greater for patients living further from their attending nephrologist. This was particularly evident for infectious causes.
Littenberg, et al. [55] USA	Type 2 diabetes	Vermont Diabetes Information System. Adults completed postal surveys and were interviewed at home. Years Unknown Sample = 781 (131 insulin users & 650 non users)	Glycaemic Control Insulin Use	Shortest driving distance Using ArcView 3.3 by ESRI and a geographic data set of roads from TeleAtlas. Distance was treated as a continuous and categorical variable. Distances were grouped as <10km & > 10 km	Patient home address TO Primary care facility	The study found that insulin users had shorter driving distances to the healthcare facility than non-users. Longer driving distances were associated with poorer glycaemic control. The OR for those using insulin, living <10km, having glycaemic control was 2.29 (CI 1.35, 3,88; p = 0.002).

Strauss, et al. [56] USA (Data cross over with [55])	Diabetes	Vermont Diabetes Information system. Adults completed postal surveys and were interviewed at home (23% of the contacted population) July 2003 - March 2005 Sample = 973 (794 non insulin users & 179 insulin users)	Glycaemic Control (for insulin and non insulin users)	Shortest Driving Distance Using a road network in ArcvIEW 3.3. Distance was modelled as a categorical variable. Patients were split into 3 equal groups <3.8km, 3.9 - 13.3km, ≥13.3km	Patients home address TO Primary care facility used.	The study identified that longer driving distances from the patient's home to the site of primary care were associated with poorer glycaemic control.
Zgibor, et al. [57] USA	Diabetes	7 diabetes management centres in Southwestern Pennsylvania. Jun 2005 - Jan 2007 Sample = 3,369	Controlled vs uncontrolled diabetes	Road Distance. Driving distance using the network analyst tool in ArcGIS. Distance was treated as a continuous and categorical variable. Distance was divided into 2 categories ≤10 miles and >10 miles. The average distance was 13.3 miles.	Patient home address (geocoded) TO The diabetes treatment centre that they attended.	The study found that living > 10 miles away significantly contributed to lower levels of glycaemic control. Those who lived ≤ 10 miles from the diabetes treatment facility were 2.5 times more likely to have improved their levels of glycaemic control between their first and last visits.
Redhage, et al. [58] USA	Liver Disease	Hospital Data and HRQOL (Health Related Quality of Life) survey. Dates unknown Sample = 2066	Longitudinal HRQOL was measured using the SF-36 Health Survey and a rolling enrolment process.	Distance Distance treated as a continuous variable. The distance range was 0 – 2261 miles and average 179.	Patients home address TO The transplant centre	The study found that increased distance to the transplant centre was associated with a decreased post-transplant health related quality of life score.
Goldberg, et al. [59] USA	Liver Transplant	Veterans Health administrations integrated, national electronic medical records linked to organ procurement and transplantation network 2003 - 2010	Being waitlisted for a liver transplant, having a liver transplant and mortality	Straight-line distance. Distance as a continuous & categorical variable. 5 distance categories: 0 - 100miles, 101-200, 201-300, 301-500, >500miles	Veterans Admission (VA) Centre TO The Veterans Admission Transplant Centre (VATC)	The greater the distance from a VATC or any transplant centre was associated with a lower likelihood of being put on a waiting list or receiving a transplant and greater likelihood of death.

		Sample = 50,637				
Zorzi, et al. [60] USA	Liver Transplant	United Network for Organ Sharing Jan 2004 – July 2010 Sample = 5,673	Mortality & being dropped from a waiting list due to being too sick.	Straight-line distance. using ww.zip-codes.com Distance was considered as a continuous & categorical variable and divided into the following 3 groups: <30miles, 30 -60 miles and >60 miles	Patients residence TO The nearest liver specialised transplant centre & nearest 300 bed hospital.	The study found that increased distance from a specialised liver transplant centre was associated with an increased likelihood of death. The likelihood of wait list drop out was significantly higher for patients living > 30 miles from the specialised liver transplant centre.
Thabut, et al. [61] USA	Lung Transplant	Transplant Registry 2001- 2009 Sample = 14,015	Listing for a transplant, receipt of a transplant and survival.	Straight-line Distance. Using ArcGIS Software. Distance was treated as a categorical variable using two different sets of groupings. Firstly - the following groups - 0 - 50 miles, 51 - 100 miles, 101 - 150 miles, 151 - 200 miles and > 200 miles. Secondly - 6 categories 0 - 50th percentile, 50th - 75th percentile, 75th - 90th percentile, 90th to 95th percentile, 95th - 99th percentile and + 99th.	Centroid of the residential zip code TO The nearest adult lung transplant centre	The study found that the distance from a lung transplant centre was inversely associated with the hazard of being listed (both before and after the introduction of the lung allocation score). Once waitlisted distance from the closest centre was not associated with differences in survival.
Lake, et al. [62] UK	TB - treatment with full course of anti TB therapy	National enhanced TB surveillance system (ETS) 2001 - 2006 Sample = 21,954	Completion of TB Treatment	Road Distance. Distance was treated as a categorical variable using the groups of < 7.3km and > 7.3km.	Home Postcode TO The TB treatment facility	The results indicate that attending a TB centre with low case load or greater distance was associated with poorer treatment outcomes. The study identified that distance to a TB treatment centre was insignificant for patients born in the UK

Lara, et al.[63] USA	Obesity	Gundersen Lutheran Medical Centre data. Sept 2001 - April 2003 Sample = 150	Compliance with follow up at 3, 6 ,9 and 12 month appointments	Straight-line Distance. Distances were treated as a categorical variable using groups: <50 miles 50 - 100 miles and >100 miles	Home Zip Code TO The Clinic they were treated/followed up at	The study found that travel distance from the clinic did not significantly affect compliance at the initial follow-up, 3-month, and 12-month appointments. However, distance did affect compliance at the 6-month appointment and significantly affects compliance at the 9-month appointment.
Jennings, et al.[64] UK	Obesity (Laparoscopic adjustable gastric banding - LAGB)	Hospital Database. < 2010. Sample = 227	Compliance with follow up appointments.	Road Distance. Calculated using google maps. Distance was treated as a continuous variable. The average distance for perfect attenders is 15.3 miles and non-attendees are 21.1.miles.	Home Address TO The treating hospital	The study identified that compliance with follow up following LAGB is associated with better weight loss Patients living closer to the treating hospital were more likely to regularly attend follow up. The study reported longer public transport journey times in the non-attending group - but did not include this in the analysis.
Sivagnanam and Rhodes[65] UK	Obesity - Laparoscopic adjustable gastric band (LAGB)	The Norwich Spire Hospital. October 1997 - March 2009. Sample = 150	Follow up and weight loss	Distance. Method not reported. Distance was treated as a categorical variable. Distance was split into the following distance groups <10, 10 - 20, 20 - 30 and > 30. (all miles) 87% of the patients lived < 50 miles from the hospital.	Patients home TO The Norwich Spire Hospital.	The study found that patients attended fewer follow up clinics, as distance increased from the patient's home address. The percentage estimated weight loss was lowest in the group that lived furthest from the hospital, but this was not statistically significant.
Jones, et al.[66] UK	Asthma	Regional Deaths System for East Anglia. 1985 - 1995 Sample = 768 (of which asthma was the underlying cause of death in 365 of these).	Mortality	Travel times. Travel times were treated as categorical & continuous variables. The groupings used for travel to the GP were 0 - 4mins >4 - 6 mins, >6 - 9 mins and ≥ 9mins. The minimum travel time was 3 minutes and the maximum 20.8 minutes. The groupings used for travel time to the hospital were 0 - 10, > 10 - 20, > 20-30, ≥ 30mins. The minimum time to	Residential Ward (average number of households = 2,726) TO The nearest GP and the nearest acute hospital with over 200 beds.	The study identified an association between asthma mortality and increasing travel time to the nearest acute hospital. The study found no relationship between distance to the GP and asthma mortality rates.

				the hospital was 4.4 minutes and the maximum 54.7 minutes.		
McCarthy, et al. [67] USA	Mental Health - Schizophrenia or bipolar disorder	National Veterans Affairs (VA) administrative data. Patients who received a diagnosis of schizophrenia or bipolar disorder in the year Oct 1997 - Sept 2008 and survived the year. Sample = 163,656	Continuity - measured by time to first 12 month gap in VA health services utilisation	Straight-line distance. Distance was treated as a continuous variable. Average distance to the nearest provider was 11.8 miles.	Population centroid of the patients zip code of residence TO The nearest VA providers of substantial psychiatric services or community based outpatient clinics serving at least 500 unique patients where at least 20% were mental health visits.	The study found that patients who had a 12 month gap in VA services utilisation were more likely to have a lower Charlson comorbidity score and live further away. Living ≥25 miles from VA care was associated with a greater likelihood of a gap in VA health utilisation. The hazard ratio associated with each 5 miles further from psychiatric services was 1.011.
Joseph and Boeckh [68] CANADA	Mental Health	Provincial health records 1976 Sample = 1767 inpatients & 883 outpatients	Seriousness of diagnosis	Distance. Distance from Peterborough Ontario. They do not provide any other information on method of calculation.	Patients residence TO Peterborough Ontario	The study concluded that severity of diagnosis increased as distance travelled increased.
Skarsvag and Wynn [69] NORWAY	Psychiatric	Regional population & actual patient data from the Stokmarknes Clinic in Nordland 1992 - 1996 Sample = 10,996 (total population) Sample = 1,834 treated population.	Use of an outpatient clinic	Travel Time. Calculated from information gathered from local bus and ferry companies. The study treated travel time as a categorical variable using the cut off of 35 minutes.	All residential addresses in the local area & actual patient attendees. TO The outpatient clinic at Stokmarknes.	The study found that a significantly higher proportion of those living < 35 mins from the clinic had used the clinics services.
Prue, et al. [70] USA	Alcohol Abuse	Jackson Veterans Administration Hospital. Years Unknown, Sample = 40.	Aftercare attendance.	Road distance. Calculated as total miles + split up into “miles to “ the nearest highway and “miles on” the nearest highway. Distance was treated as a	Patients home TO The aftercare facility	The study found that the number of “miles to" and "miles on" the highway significantly affected the probability of attendance at alcohol abuse aftercare. Distance to the major highway was more predictive of attendance than the miles on the major highway.

				continuous variable. The range of distances was (12 - 378 miles).		
Monnet [71]2008) FRANCE	Hepatitis C	Registry Data 1994 - 2001 sample = 1,938	Hepatitis C detection rates	Road Distance. Using Chrono map in MapInfo with the 1997 Michelin light road network table (major roads). Distance was treated as a continuous variable.	Geometric centroid of the patients municipality of residence TO The geometric centroid of municipality of the GP	The study found that the detection rate for Hepatitis C decreased in each of the studies socioeconomic clusters as distance to the GP increased.
Jackson, et al. [72] USA	Elective Pancreatic Surgery	Local National Surgery Quality Improvement database. 2005 - 2011 Sample = 243	Length of Stay	Road distance with the shortest travel time. Distance was treated as a continuous variable. The distances ranged from 3 - 3006 miles.	5 digit zip code of the patients primary residence TO The 5 digit zip code of the hospital.	The study found that for each additional 100 miles travelled, the length of hospital stay increased by 2%.
Jackson, et al. [73] USA	Colorectal Surgery	The National Surgical Quality Improvement Programme Database. May 2003 - April 2011 Sample = 866	Length of Stay	Road distance & shortest travel time. Distance was treated as a continuous variable. The mean distance travelled was 146.9 miles (range 2 - 2984). The study transformed distance and length of stay onto the log scale due to non-normal distributions.	5 digit zip code of the patients primary residence TO The 5 digit zip code of the hospital.	The study found that in the adjusted model increased travel distance from a patient's residence to the hospital was associated with an increase in length of stay.
Haynes, et al. [74] UK	Inpatient Episodes	Regional Health Authority. 1991 - 1993 Sample = 470,650 acute episodes, 13,425 psychiatric episodes and 36,909 geriatric episodes.	Healthcare episodes	Straight-line distance. Distance was treated as a continuous variable. The furthest distance to the GP was 8km and to the acute hospitals 41km.	Population weighted centroid of the ward the patient lived in TO the nearest district general hospital. & Population weighted centroid of the enumeration district the patient lived in TO The nearest GP surgery.	The study found that after controlling for confounders distance to hospital was a significant predictor of hospital episodes, especially psychiatric episodes. The study found that distance to the GP was only significantly associated with reductions in acute episodes in hospital.
Arcury, et al. [75] USA	Non specific - Health care	Survey of adults in 12 rural Appalachian	Number of regular check-up care	Straight-line distance.	Survey respondents homes	The study found that distance was significantly associated with the number of regular check-up care

	visits	North Carolina Counties. Personal interviews in participants homes. 1999 - 2000. Sample = 1,059	visits, chronic care visits and acute care visits	Distance to the healthcare facility was based on respondents stating which hospital, clinic or doctor to which they would normally go for "a really bad emergency", A less serious emergency, and for regular care. The average distance for regular check-up visits was 14 miles, for chronic care visits 18 miles and serious emergencies 18.58miles.	TO The self-reported hospital, GP, Clinic that they would normally go to for a really bad emergency, a less serious emergency or for regular care.	visits and chronic care visits. Distance was not associated with acute care visits. They identified that those people with a driving license had an estimated 1.58 times more regular care visits and 2.3 times more chronic care visits.
Ballard, et al. [76] USA	Non-specific.	Medicare hospitalization data (MEDPAR) 1998 Sample = 13,596 Two groups – patients referred to Mayo Rochester hospitals and separately national referral hospitals.	30 day mortality	Distance No information in paper on specific method. Distance was split into the categories of <10 miles and ≥ 10 miles.	Patients residential zip code TO Zip code of the hospital attended	The study presented results that showed that increased distance from the patient's home address to the hospital that they were treated in was independently associated with higher 30 day mortality rates.
Etzioni, et al. [77] USA	Any Surgical Operation	National Surgical Quality Improvement Project (NSQIP) database - for a large tertiary care institution. 2006 - 2009 Sample = 6,938 procedures	30 day surgical outcomes	Distance No information on method. Distances travelled were treated as a categorical variable and split into quintiles by procedure category. This allowed the study to take into account that patients travelled further for more complicated operations. The average distance was 226 miles.	Residential zip code centroid TO The attending tertiary hospital.	The study found that patients who lived closer were less likely to have a serious complication at 30 days and had better outcomes than predicted.

Table 3: Included studies identifying a distance bias relationship

Author Country	Disease / Procedure	Source, Years & Sample size	Health Outcome	Distance/ travel time measurement	Origin and Destination	Summary of key results
Lipe, et al. [78] USA	Bone Marrow Transplant for Multiple Melanoma	Dartmouth Hitchcock Medical Centre transplant registry 1996 - 2009 Sample = 77	Survival (OS and progression free survival)	Straight-line Distance. The study used the website www.melissadata.com. Distance was treated as a continuous variable and categorical variable split into the groups of < 50miles and > 50 miles	Patients Home TO The Dartmouth Hitchcock Medical Centre	The study found that increasing distance from the transplant centre was associated with improved overall survival. The authors identified that this could be due to a referral bias, but could also be due to a healthier and more motivated groups of patients living further away.
Wasif, et al. [79]	Gastrointestinal Cancer	National Cancer Database. 2003 – 2009 Sample = 77	Survival	Distance. Does not stated the method. Distance was treated as a continuous variable and categorical variable split into the groups of <50 miles and >50 miles	Patient residence – zip code centroid TO The treatment facility zip code centroid	The study found that adjusted hazard ratios were significantly lower for patients travelling > 50 miles compared to < 50 miles. This was true for liver, oesophageal and pancreatic cancer. They concluded that those that travelled > 50 miles to the treatment facility had lower 30 day mortality rates.
Lenhard Jr, et al. [80] USA	Multiple Myeloma	Centralised Cancer Patient Data System. 1977 - 1982. Sample = 1,479	Survival	Distance. Distance was treated as a categorical variable using the following groups - 0 - 9 miles, 10 - 49 miles, 50 - 149 miles, and ≥ 150miles	Patient zip code TO The treating centre zip code area	The study found that survival improved with increasing distance travelled to treatment centres.
Lamont, et al. [81] UK	Cancer	4 phase II chemo radiotherapy studies conducted at the University of Chicago. 1993 - 2000 Sample = 110.	Survival	Distance. Driving miles (using an "internet based mapping engine"). Distances were categorized into two groups ≤ 15 miles (45 patients) and > 15 miles (67 patients)	Patient Residence (exact address) TO The University of Chicago hospital	The study found a positive association between the distance that patients travelled and survival. Those living > 15 miles had only 1/3 of the hazard of death than those living ≤15 miles. With every 10 miles that a patient travelled the hazard of death declined by 3.2%.
DeNino, et al. [82] USA	Gastric Band	Teaching hospital patients Nov 2008 - Nov 2009 Sample = 116	Follow Up Compliance and Weight Loss	Road Distance. Calculated using Google maps. Distance was treated as a continuous variable. The average distance to the hospital was 39.5 miles.	Patients Home To The Treating Hospital	The study found a weak relationship between increased travel distance to the hospital and increased weight loss. Travel distance was found not to be significant for attending follow up visits.

Table 4: Included studies identifying no relationship

Author Country	Disease / Procedure	Source, Years & Sample size	Health Outcome	Distance/ travel time measurement	Origin and Destination	Summary of key results
Gunderson, et al. [83] USA	Cervical Cancer	Medical Records 2006 - 2011 Sample = 219	Survival	Straight- line Distance. Distance as a categorical variable. Using the following groups: <30 miles and >30 miles	Zip code of patient residence TO The Treating Hospital (if the patient underwent surgery and radiation centre)	The study found no significant difference between patients travelling <30 miles and those travelling >30 miles for survival. They found that non Caucasians were less likely to travel > 30 miles.
Celaya, et al. [84] USA	Breast Cancer	New Hampshire State Cancer Registry (NHSCR) 1998 - 2004 Sample = 5,966	Stage at diagnosis	Driving time and driving distance. Calculated using ArcGIS and data from ESRI on street networks, posted speed limits and driving distance. Distance and travel time were treated as categorical variables. Using the following groupings: < 5 miles, 5 - <10 miles, 10 - < 15.0 miles, ≥15 miles. For travel time < 5 mins, 5 - < 10 mins and ≥ 10 mins	Residence (Addresses of patients were geocoded to an exact street address(91%) or to the zip code centroid if only a post office box or rural route address was available.) TO The nearest mammography facility.	The study identified no significant association between later stage breast cancer and travel time to the nearest mammography facility. They did identify that there was good access (patients did not have to travel a large distance) to mammography facilities in the area studied, as shown by the categorical groupings.
Meersman, et al. [85] USA	Breast Cancer	California Health Interview survey 2001 Sample = 4,249	Mammography uptake	Straight-line Distance. Distances were treated as categorical variable and split into the following quartiles: 0 - 0.53 miles, 0.54 - 1.07 miles,1.09 - 1.82 miles and 1.83 - 26.5 miles. The study also calculated the number of public transit stops within 3 miles of the respondent and split these into quartiles.	Respondents Address (70% of the sample were geocoded based on the nearest street to their residence, 30% to their zip code centroid). TO The nearest mammography facility.	The study did not use the distance calculations in the final model (as they were not significant)- but used mammography density within 2 miles of a patient's residence instead - which was found to be significant. The number of bus stops within 3 miles was not significant. This indicated that density of mammography facilities and not distance was the critical factor
Heelan and McKenna [86] IRELAND	Cancer	Melanoma Database. 2000 - 2009 Sample = 106	Breslow Thickness	Road Distance. The automobile Association route planner was used to estimate distance travelled by road. Data was treated as a categorical variable using the groupings of < 30km and >30km. The median distance was 33.3km (range 0.2 - 123.12km)	Patients Home TO The hospital attended.	The study found no significant association between distance travelled and Breslow thickness on presentation. The study concluded that this could have been due to the type of patients in the sample (high number of thick lesions) in both distance categories.

Henry, et al. [87] USA	Breast Cancer	US North American Association of Central Cancer Registries. Patients diagnosed 2004 - 2006 Sample = 174,609	Stage at diagnosis	Travel Times. The study calculated 3 accessibility measures including Shortest road network drive time. This used the NAACCR shortest path calculator. - https://www.naaccr.org/Research/ShortestPathFinder.aspx Travel times were treated as categorical variable using the following groups - ≤ 5 mins, > 5 - 10, > 10 - 20, > 20 - 30, > 30. 93% of the breast cancer cases lived < 20 mins from the nearest mammography facility and only 2.8 % lived > 30mins.	Road nearest the population weighted centroid of each census tract TO The nearest FDA certified mammography facility	The study found that after adjusting for poverty there was no impact of distance on late stage diagnosis. They found that poverty was independently associated with late stage diagnosis.
Schroen and Lohr [88]	Breast Cancer	Virginia Cancer Registry 2000 - 2001 Sample = 8,170	Invasive tumour size at diagnosis	Shortest driving distance. Calculated using ArcGIS. Distance was treated as a continuous variable. The average distance was 5.7 miles and only 5% of the patients lived >20 miles away.	Patient home address TO The nearest mammography facility.	The study found that distance to the nearest mammography facility had no consistent relationship between invasive tumour size at diagnosis in the adjusted model. They found that only advanced age was a predictor of invasive tumour size at diagnosis
Crawford, et al. [89] UK	Colorectal Cancer	Northern and Yorkshire Cancer Registry and Information Service. 1994 – 2002 Sample = 39,619	Stage of diagnosis & receipt of treatment	Travel Time. Shortest road route and average driving speeds along the routes by road class. Travel times were split into quartiles.	Patient Home TO The closest hospital providing diagnostic and surgical treatment services for bowel cancer.	The study found no effect of travel time distance on stage of diagnosis or receipt of treatment. They also found no interaction effects between deprivation and travel time.
Cosford, et al. [90]	Cancer	Cancer Registry 1991 Sample = described as the no. of people in each local authority district attending hospital with a diagnosis of cancer and the no. who received radiotherapy in that year.	Radiotherapy uptake	Travel Times. Obtained from a "commercially available computer programme".	Population weighted centroid of 14 local authorities TO The nearest cancer centre serving the area.	The study found no significant relationship between overall radiotherapy uptake and travel times.

Henry, et al. [91] USA	Breast cancer	10 state population based cancer registries - covering 30% of the population of the USA. Patients diagnosed 2004 - 2006 Sample = 161,619	Stage at Diagnosis	Travel Time. Travel time was modelled as both a continuous and categorical variable. There were 7 categories ranging from < 10 mins to ≥ 60 mins. 76% of the women lived <20 mins from their diagnosing facility & 93% < 20mins from the nearest mammography facility.	Geocoded to the residential street address (87%) or postal delivery area centroid (8%). TO Both the diagnosing facility and nearest facility.	The study concluded that increased travel time was not a determinant of late stage diagnosis. They found that insurance status, race and poverty were associated with risks for a late stage diagnosis of breast cancer.
Sauerzapf, et al. [92] UK	Breast Cancer	Northern and Yorkshire Cancer Registry Information Service. 1994 - 2002 Sample = 6,014	Breast conserving surgery vs mastectomy & whether the patient had received radiotherapy following breast conserving surgery.	Travel Time. Fastest Travel time using the road network. Using ArcGIS and the Meridian digital road network. Sections of the road were assigned average car travel times. Distances were treated as categorical variables using the categories of ≤30 mins, 30 - 60 mins > 60 mins. The study also collected information on those living within 800m of a frequent bus service.	Home postcode of patient TO The closest hospital where radiotherapy was available.	The study found that the choice of breast conserving surgery or receiving radiotherapy was not associated with the estimated travel time. They did find that travel time to radiotherapy was only significant as a predictor of surgery choice for patients living >800 m from a frequent bus service.
Swan-Kremeier, et al. [93] USA	Eating Disorder	Contact records, clinical records and appointment records of patients at a treatment centre. Unknown date. Sample = 139 (37 completers & 102 drop outers)	Attendance Patterns and Treatment Attrition	Straight-line Distance. Distance was treated as a continuous variable. The average distance for completers was 43.9 miles and the average distance for drop outers was 29.8 miles.	Patients home To The treatment centre	The study concluded that distance travelled to the treatment site was not significantly different between the two groups (drop outers and completers).
Markin, et al. [94] USA	Pulmonary Arterial Hypertension	PAH Disease Management (REVEAL). Years Unknown. Sample = 638	Delayed diagnosis	Distance. (method not reported) Distance was treated as a categorical variable using the grouping of < 50miles vs >50 miles.	Patients home TO The pulmonary hypertension (PH) centre	The study concluded that distance from the PH centre was not shown to be associated with a delayed diagnosis, lower likelihood of early treatment with an IV/SC prostacyclin analog, or a worse functional class at diagnosis.

Stoller, et al. [95] USA	1-Antitrypsin (AAT) deficiency	The results are based on a 4 page mailed out survey to AAT deficient individuals. Achieving a 38% response rate. 2003 Sample = 1,851 (Achieving a 38% response rate)	Diagnostic delay	Distance. GIS software and zip code data were used to determine distance from a clinical resource centre (CRC) and urban/ rural residences. Distance was treated as a categorical variable using the groups of < 50 miles and ≥ 50 miles to the CRC. 38% of the survey respondents lived within 50 miles of a CRC.	Home Zip code TO the nearest designated CRC	The study found that neither urban residence nor living near a centre with expertise (living within 50 miles) was associated with a shortened delay.
Rodkey, et al. [96] USA	Heart Transplant	Transplantation hospital charts, local hospital records and direct patient and family contact. 1984 - 1995 Sample = 312	Rejection episodes, No. of endomyocardial biopsies, ED visits, hospital admissions, infections, coronary allograft vasculopathy, malignancies re-transplantation and death	Distance. Distance was calculated using the Rand McNally TripMaker Version 1.1. Distance was treated as a categorical variable using the groups 0 - 150miles 151 - 300 miles and >300miles. 207 patients lived in group 1, 69 patients lived in group 2 and 36 in group 3. (range 2 - 1218 miles)	Primary city of residence TO The transplant Centre	The study concluded that long distance management of heart transplant recipients is successful and is not associated with an increase in adverse outcomes. Patients living further away had similar results to those in the closest category.
Ragon, et al. [97] USA	Allogeneic hematopoietic stem cell transplantation (HSCT)	Transplant data team and medical records 2006 - 2012 Sample = 299	Survival	Straight-line Distance. Distance from the transplant centre was split into 2 groups of <170km and >170km. This represented a cut off at 75th percentile.	Zip code of residence at the time of the transplant TO The medical centre where they were treated.	The study found that distance did not impact on the overall survival rate.
Firozvi, et al. [98] USA	Liver Transplant	Medical Centre Transplant Database. 2002 - 2005 (censor date 2005)	Listing status, time required to list, survival once listed,	Travel Time. Calculated using Yahoo! Maps. Travel time was treated as a categorical variable using > 3 hour and ≤3 hour. 38	Homes Address (where not available the patients home town or city centre) TO	The study found that those patients living > 3 hours away from a transplant centre had comparable outcomes to those living closer.

		Sample = 166.	transplantation and 1yr post transplantation survival.	people had travel times > 3. The range of travel times was 0 - 7 hours.	The specific transplant centre	
Tonelli, et al. [99] CANADA	Kidney transplantation	Canadian Organ Replacement Registry. Patients starting dialysis 1996 - 2000 (followed until Dec 2001) Sample = 7,034	Likelihood of Transplant	Distance (No information on distance calculations). Distance was treated as a categorical variable using the groups - < 50km, 50.1 - 150km, 150.1 - 300km and > 300km.	Patients Residence (at the time of starting dialysis) TO The nearest transplant centre	The study found that the likelihood of a transplant was not affected by the distance from the closest transplant centre.
Leese, et al. [100] UK	Diabetes Related Foot Disease	Three linked data sets. Scottish Care Information Diabetes Collaboration - Tayside Regional Diabetes Register, Foot ulcer dataset, Amputation dataset. 2004 - 2006 Sample = 15,983. 670 (with new foot ulcers) 99 (with an amputation)	Occurrence of a new foot ulcer or amputation	Travel Time. Using the road network. Travel time was treated as a continuous variable. The average time to the GP was 6.48 minutes, average time to the local hospital was 28.47 minutes.	Residential Location TO The local hospital clinic & local GP	The study concluded that distance from the GP or hospital clinic and lack of attendance at community retinal screening did not predict a foot ulceration or amputation. Being socially deprived was significantly associated with foot ulceration.

The studies were diverse in nature; however four out of five of the distance bias studies (table 3) reported a positive relationship between increasing travel distance and better survival rates for cancer ([78]-[81]). [78] concluded that survival rates were higher for those travelling further to the transplant centre in their study potentially due to referral bias, but also patients living further away being healthier and more motivated. Other effects identified by the review include the study by [31] who highlighted a U shaped all-cause mortality relationship. When the data was split into 3 categories, those in the middle (20 – 30 km) category had lower all-cause mortality than those living in the closer or further away categories. Indicating that there was something different about this geographical area and the people living in it. This effect was evidence in other papers, but not at statistically significant levels.

Over 50% of the studies focused on cancer (49% in table 1, 80% in table 2 and 56% in table 3) with the majority of these being breast or colorectal cancer studies. Other diseases and outcomes are summarized in tables 2 - 4. The studies also covered a wide range of contexts and travel requirements for patients. Studies that identified a distance decay relationship ranged from a very localised cohort of patients - average distances to the healthcare facility of 13.3 miles for treatment for diabetes [57], to > 6 hours travel in Canada for breast and colorectal cancer survival [16], to > 300km for remote kidney dialysis [53], and an inter country study with a range of 1km – 870km for treatment for malignant brain tumour [40]. These differences reflect both the geographical sizes of the countries in question and the need to travel for specialist treatment. There was no obvious difference in the distances and travel times between the three groups (distance decay, distance bias and no relationship) and a distance decay relationship was evident across a wide range of distances.

A wide variety of methods and data (e.g. registry data, patient surveys, hospital data) were used to explore the relationship. There were differences in the patient origins and healthcare destinations used to determine the patient journeys. The majority used the patients address (e.g full address/postcode/ zipcode) as the origin for the journey, but others used the centroids of larger geographical areas ([47], [15],

[66],[26]) or the referring hospital [59] or the city of residence [96]. It was recognised that for longitudinal studies there was a potential for patients to move addresses. [34] applied the residential location at the time of diagnosis and assumed this remained constant during treatment. 60% of the studies had access to data on nearest healthcare facility to the patient, with the remainder using the actual healthcare facility attended. Certain studies ([28], [91]) calculated both the nearest and actual facility attended to compare.

The method for calculating travel distance/ travel time in the studies ranged from straight-line distance (Euclidean Distance), travel distance using a road network; travel speed using the shortest distance by road network (with and without adjusted road network speeds) or patients self-reported travel times. As shown in table 1over 20% of the studies did not clearly state how they had calculated this variable. 100% of the studies in the distance bias group calculated distance, 72% in the distance decay group and 56% in the group that identified no relationship.

DISCUSSION

The results were mixed. 70 studies identified evidence of distance decay, 18 no effect and 5 studies evidence of distance bias. The majority of studies provided evidence that their statistical models predicted that the further the patient had to travel (distance or travel time) to access healthcare facilities led to worse health outcomes. This was true across a multitude of disease groups and geographical distances and boundaries. The range of methods, sources of data, disease areas and outcome measures and ranges of distances travelled identified add to the complexity of the comparisons. The focus of this discussion is on the key differences in the way that the distances and travel times were calculated and analysed and what observations from the studies have heightened potential reasons to suggest an association between distance/ travel time and health outcomes.

Travelling to healthcare

The critical elements of calculating an accurate representation of the distances and travel times that the patients have endured requires a starting location for the journey (e.g. patient home address) [1], end point (healthcare facility) and method for accounting for the estimated route taken between these two points. The included studies differed on all three of these areas. Where the patients address (most accurate proxy measure) was unavailable less specific geographical identifiers were provided, ranging from patients postcode [62] , zip code centroid [10], centroid of a census district [47] to treated hospital [59], to the centroid of town of residence [96] to a mixture of the above methods where data was missing at the less aggregated geographical levels [84]. Using an origin point that is less accurate than the patients home address, has the potential to reduce the accuracy of the results, as it may influence the route taken affecting the distances and travel times.

The geographical data available for the healthcare facilities attended also differed across studies. 40% of the studies had the address of the healthcare facility attended by the patient, but the majority used the address of the nearest facility to the patient, as a proxy. In [29] only 37% of the patients attended the nearest facilities. Knowing how realistic the proxy measure is to reality would be a benefit.

One issue identified by the studies was that where patients were followed up over time - patients had the potential to move home address ([34], [46]). In was argued by certain studies that grouping distances into large categorical bands allowed patients to move residence, but not actually move categories during the study. For example this worked for [45], whereby 27% of the study's population changed their residence during the 5 year follow up, but 91% of the patients had remained in the original distance category.

The majority of studies focused on one destination (e.g. hospital attended), for one type of treatment (e.g an operation), but this has the potential to underestimate the impact of distance/ travel times on health outcomes – where patients are potentially making multiple trips to a range of hospitals over the course of

[1] It is noted that not all patient journeys start from the patient's home address. This is therefore a proxy measure.

the year for a range of health issues. To try and be more representative of the travel burden [32] used the follow up radiation centre address as the destination for patients rather than the place they had the surgery, as they argued patients would have to make this journey more frequently. Studies such as [14] considered the impact of a range of potential healthcare settings (e.g. distance to the nearest cancer centre, GP, hospital of first referral). This study identified a significant relationship between distance and survival only for the location of the GP. Similarly [13] found that as travel times to the nearest GP increased patients were more likely to have a later stage breast cancer diagnosis, which was not evident when focusing on the distance to the nearest mammography service. These two examples imply that focusing on a specific healthcare location could be missing the location that influenced the patient health outcomes.

Measuring distance and travel time

Euclidean distance was used to calculate the distance for >25% of the studies. It is unlikely that any healthcare trip can be made in a straight – line, but it was argued by certain studies that grouping distances into categories that covered large geographical areas, reduced the effects of differences between using real road distance and straight-line distance. The remainder of the studies calculated drive time or drive distance. A number of studies did take account of the time of year to control for potential differences in the weather and the impact this might have ([84]), but none included traffic congestion to calculate the travel times, which could significantly have increased the travel times included.

Distances and travel times were included in the statistical models as continuous or categorical variables or both separately. One of the key issues identified by the studies was that distances/ travel times tended to be positively skewed towards more patients living closer to the healthcare facilities that they were attending. In order to better represent this phenomenon [15] split the travel times into the following categories to take account of this - lowest quartile, medium (quartile 2 and 3), high (75th –95th percentile) Highest (95th– 100th percentile). Other studies linearized distance/ travel time from the natural scale to the log scale, but the majority did not. For studies that included distance/ travel times as a categorical variable there was no consensus on what categories should be used. Study examples include, [60] who split the travel distances into < 30 miles, 30 – 60 miles and > 60miles, [11] used dichotomous categories < 300km and > 300km and [63] split data into < 10 km and ≥ 10 km [63]. Other studies used quartiles or quintiles. In many cases no justification was given for how the categories were determined, which has the potential to hide effects, where critical thresholds are missed. What the studies did identify was that the results were sensitive to the cut offs used in the model. [75] found that after adjusting for age the likelihood of receiving radiotherapy following Breast conserving surgery decreased significantly with increasing travel distance to the nearest facility for distances >74.9miles compared to <10miles, but not for categories in-between. In this case a dichotomous threshold that compared < 30 and ≥ 30 might not have picked up this effect. [39] and [12] presented results that were only significant in the model that treated distance as a continuous variable, again the categories might not have been sensitive enough to pick up any effect. 84% of the studies that identified no relationship treated distance/ travel time as a categorical variable.

Mode of transport

It was assumed in the majority of studies that patients would travel by car. Exceptions include [69], [75], [48], [64]. [48] reported that increased public transport travel time contributed to missing kidney dialysis sessions. For some patients (potentially in the most deprived groups) it will not be possible to access healthcare by car. [64] found that public transport travel times were longer for patients who did not attend follow up appointments compared to those that did. Other studies included public transport access through proxy measures (e.g. whether patients were within 800m walking distance of an hourly bus service). Issues with this include that it does not account for whether the bus goes to the hospital, the travel time once on the bus or the likelihood of an ill patient being able to walk 800m. A travel survey completed for [89] found that 87% (not 100%) of the trips to that hospital were made by car. To ensure representative travel times/ distance it is critical to understand the patient population (in this case how they are travelling) and not just assume that all patients have and can travel to the facilities by car.

Key Relationships

Key observations from the studies showed that the distance decay relationship was more pronounced for less serious illnesses [64], as a predictor of attendance at regular check-up visits[75], for patients skipping in-between follow up appointments (e.g. attending 3 and 12 months but not 6 and 9 months)[63], for patients not native to the county they were being treated in [62], at the one year after a transplant point and not before [39] and patients in more deprived areas [89]. All of which could be considered when tailoring healthcare provision.

One of the key influencing variables identified by the studies was deprivation. [34] found that when controlling for deprivation that the effect of distance on health outcomes was removed, whilst [89] that distance amplified the effect from deprivation. From one side it might be argued that by controlling for deprivation this is also removing some of the impact of distance/ time that is experienced by those who do have access to a car and would have to travel by other means. For those studies in the review not controlling for deprivation may be over estimating the true impact of distance travelled/ travel time on patient's health.

Strengths and Limitations

This systematic review has for the first time synthesized available evidence on the association between differences in travel time/distance to healthcare services and patient's health outcomes. It has identified a wealth of studies and generated evidence for wide range of disease groups and health outcomes, across multiple countries. There was great variation in study design, distances and travel times to the healthcare setting, and range of health outcomes; this precluded pooling of data for meta-analysis. The study followed a search strategy to maximise the identification of relevant studies of which 18 did not find a relationship between distance/ travel time and health outcomes; this is likely to be an underrepresentation if authors have a tendency to not publish results that showed no effect. While the review findings are of undoubted value in broadening our understanding of the wider societal factors that influence health outcomes, their applicability may be limited to countries with similar healthcare systems.

CONCLUSIONS

In a debate between locally vs centralisation of healthcare provision, 75% of the included studies showed evidence of an association between worse health outcomes and the further a patient lived from the healthcare facilities they needed to attend. This was evident at all levels of geography – local level, interurban and inter country level. A distance decay effect cannot be ruled out and distance/ travel time should be a consideration when configuring the locations of healthcare facilities and treatment options for patients.

Footnotes

Contributors: CK wrote the protocol with critical input from CH, GC, and TF. CK developed the search strategy and did the electronic searches. CK and CH screened the titles and abstracts and selected studies for inclusion. CK and CH carried out the data extraction and quality assessment. CK wrote the original draft and CH, GC and TF revised the draft critically for important intellectual content and approved the final version of the paper.

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REFERENCES

1. Woo Y, Kyrgiou M, Bryant A, et al. Centralisation of care may prolong survival in women with ovarian cancer and possibly more generally gynecological cancer. Secondary Centralisation of care may prolong survival in women with ovarian cancer and possibly more generally gynecological cancer 2012. http://summaries.cochrane.oorg/CD007945/centralisation-of -care-may-prolong-survival-inwomen-with-ovarian-cancer-and-possible-more-generally-gynaecological-cancer.
2. Morris S, Hunter RM, Ramsay AIG, et al. Impact of centralising acute stroke services in English metropolitan areas on mortality and length of hospital stay: difference-in-differences analysis. Bmj 2014;**349**.
3. Haynes R. Geographical access to healthcare. In: Guilliford M, Morgain M, eds. Access to Healthcare. London, 2003:13-35.
4. Goddard M, Smith P. Equity of access to healthcare. York: Centre for Health Economics. Secondary Equity of access to healthcare. York: Centre for Health Economics 1998. https://www.york.ac.uk/che/pdf/op32.pdf.
5. Hunter J, Shannon G. Jarvis revisited: Distance decay in service areas of mid - 19th century asylums. The professional Geographer 1985;**37**(3):296 - 302.
6. Sackett D, Richardson W, Rosenberg W, et al. *Evidence -based medicine: how to practice and teach EBM.* . New York: Churchill Livingston, 1997.
7. CASP. Critical Appraisal Skills Programme. Secondary Critical Appraisal Skills Programme 2015. www.casp-uk.net/.
8. Punglia R, Weeks J, Neville B, et al. Effect of distance to radiation treatment facility on use of radiation therapy after mastectomy in elderly women. International Journal of Radiation Oncology Biology Physics 2006;**66**(1):56-63.
9. Nattinger AB, Kneusel R, Hoffman R, et al. Relationship of distance from a radiotherapy facility and initial breast cancer treatment. J Natl Cancer Inst 2001;**93**(17).
10. Engelman K, Hawley D, Gazaway R, et al. Impact of geographic barriers on the utilization of mammograms by older rural women. J Am Geriatr Soc 2002;**50**(1):62-68.
11. Panagopoulou P, Gogas H, Dessypris N, et al. Survival from breast cancer in relation to access to tertiary healthcare, body mass index, tumor characteristics and treatment: a Hellenic Cooperative Oncology Group (HeCOG) study. Eur J Epidemiol 2012;**27**(11):857-66.
12. Maheswaran R, Pearson T, Jordan H, et al. Socioeconomic deprivation, travel distance, location of service, and uptake of breast cancer screening in North Derbyshire, UK. J Epidemiol Community Health 2006;**60**:208-12.
13. Wang F, McLafferty S, Escamilla V, et al. Late-stage breast cancer diagnosis and health care access in illinois. Professional Geographer 2008;**60**(1):54-69.
14. Jones AP, Haynes R, Sauerzapf V, et al. Travel times to health care and survival from cancers in Northern England. Eur J Cancer 2008;**44**(2):269-74.
15. Haynes R, Pearce J, Barnett R. Cancer survival in New Zealand: ethnic, social and geographical inequalities. Soc Sci Med 2008;**67**(6):928-37.
16. Cramb SM, Mengersen KL, Turrell G, et al. Spatial inequalities in colorectal and breast cancer survival: premature deaths and associated factors. Health Place 2012;**18**(6):1412-21.

17. Jones AP, Haynes R, Sauerzapf V, et al. Geographical access to healthcare in Northern England and post-mortem diagnosis of cancer. J Public Health (Oxf) 2010;**32**(4):532-37.

18. Schroen A, Brenin D, Kelly M, et al. Impact of patient distance to radiation therapy on mastectomy use in early-stage breast cancer patients. Journal of Clinical Oncology 2005;**23**(28):7074-80.

19. Athas W, Adams-Cameron M, Hunt W, et al. Travel Distance to Radiation Therapy and Receipt of Radiotherapy Following Breast-Conserving Surgery. J Natl Cancer Inst 1999;**92**(3):269-72.

20. Meden T, St John -Larkin C, Hermes D, et al. Relationship between travel distance and utilization of breast cancer treatment in rural northern Michigan. JAMA - Journal of the American Medical Association 2002;**2287**(1):111.

21. Celaya MO, Rees JR, J.J. G. Travel distance and season of diagnosis affect treatment choices for women with early stage breast cancer in a predominantly rural population. Cancer causes & control : CCC 2006;**17**(6):851-6.

22. Huang B, Dignan M, Han D, et al. Does distance matter? Distance to mammography facilities and stage at diagnosis of breast cancer in Kentucky. J Rural Health 2009;**25**(4):366-71.

23. Jethwa K, Settergren B, Berg B, et al. Association between travel distance to a comprehensive cancer center and breast cancer stage, treatment, and outcomes in a rural state. Cancer Prevention Research 2013;**1)**.

24. Onitilo AA, Liang H, Stankowski RV, et al. Geographical and seasonal barriers to mammography services and breast cancer stage at diagnosis. Rural and Remote Health 2014;**14**(3).

25. Crawford SM, Sauerzapf V, Haynes R, et al. Social and geographical factors affecting access to treatment of lung cancer. Br J Cancer 2009;**101**(6):897-901.

26. Brewer N, Pearce N, Day P, et al. Travel time and distance to health care only partially account for the ethnic inequalities in cervical cancer stage at diagnosis and mortality in New Zealand. Australian and New Zealand Journal of Public Health 2012;**36**(4):335-42.

27. Burmeister BH, Zarate DD, Burmeister EA, et al. Lung cancer patients in Queensland suffer delays in receiving radiation therapy - but not as a result of distance. Intern Med J 2010;**40**(2):126-32.

28. Bristow RE, Chang J, Ziogas A, et al. Spatial analysis of adherence to treatment guidelines for advanced-stage ovarian cancer and the impact of race and socioeconomic status. Gynecol Oncol 2014;**134**(1):60-67.

29. Tracey E, Hacker NF, Young J, et al. Effects of Access to and Treatment in Specialist Facilities on Survival From Epithelial Ovarian Cancer in Australian Women A Data Linkage Study. Int J Gynecol Cancer 2014;**24**(7):1232-40.

30. Holmes JA, Carpenter WR, Wu Y, et al. Impact of distance to a urologist on early diagnosis of prostate cancer among black and white patients. J Urol 2012;**187**(3):883-8.

31. Kim YE, Gatrell AC, Francis BJ. The geography of survival after surgery for colo-rectal cancer in southern England. Social Science and Medicine 2000;**50**(7-8):1099-107.

32. Dupont-Lucas C, Dejardin O, Dancourt V, et al. Socio-geographical determinants of colonoscopy uptake after faecal occult blood test. Dig Liver Dis 2011;**43**(9):714-20.

33. Fournel I, Cottet V, Binquet C, et al. Rural - Urban inequalities in colorectal adenoma detection rates in the general population. Ann Oncol 2010;**21**:vi57.

34. Dejardin O, Jones AP, Rachet B, et al. The influence of geographical access to health care and material deprivation on colorectal cancer survival: Evidence from France and England. Health and Place 2014;**30**:36-44.

35. Anderson AE, Henry KA, Samadder NJ, et al. Rural vs Urban Residence Affects Risk-Appropriate Colorectal Cancer Screening. Clinical Gastroenterology and Hepatology 2013;**11**(5):526-33.

36. Campbell N, Elliott A, Sharp L. Rural and urban differences in stage at diagnosis of colorectal and lung cancers. Br J Cancer 2001;**84**(7):910-4.

37. Baade PD, Dasgupta P, Aitken JF, et al. Distance to the closest radiotherapy facility and survival after a diagnosis of rectal cancer in Queensland. Med J Aust 2011;**195**(6):350-4.

38. Lavergne MR, Johnston GM, Gao J, et al. Variation in the use of palliative radiotherapy at end of life: examining demographic, clinical, health service, and geographic factors in a population-based study. Palliat Med 2011;**25**(2):101-10.

39. Abou-Nassar KE, Kim HT, Blossom J, et al. The Impact of Geographic Proximity to Transplant Center on Outcomes after Allogeneic Hematopoietic Stem Cell Transplantation. Biology of Blood and Marrow Transplantation 2012;**18**(5):708-15.

40. Kerschbaumer J, Freyschlag CF, Bauer R, et al. Distance to the neurooncological center: a negative prognostic factor in patients with glioblastoma multiforme. An epidemiological study. Anticancer Res 2012;**32**(12):5515-9.

41. Campbell N, Elliott A, Sharp L, et al. Rural factors and survival from cancer: analysis of Scottish cancer registrations. Br J Cancer 2000;**82**(11):1863-6.

42. Jones A, Haynes R, Sauerzapf V, et al. Travel time to hospital and treatment for breast, colon, rectum, lung, ovary and prostate cancer. Eur J Cancer 2008;**44**(7):992-9.

43. Chou S, Deily ME, Li S. Travel distance and health outcomes for scheduled surgery. Med Care 2014;**52**(3):250-7.

44. Singh D, Jaiswal V, Sonkar AA, et al. Randomized control trial of conventional laparoscopic versus single incision laparoscopic cholecystectomy. Hpb 2014;**16**:115.

45. Thompson S, Gill J, Wang X, et al. Higher mortality among remote compared to rural or urban dwelling hemodialysis patients in the United States. Kidney Int 2012;**82**(3):352-9.

46. Bello AK, Hemmelgarn B, Lin M, et al. Impact of remote location on quality care delivery and relationships to adverse health outcomes in patients with diabetes and chronic kidney disease. Nephrol Dial Transplant 2012;**27**(10):3849-55.

47. Judge A, Caskey FJ, Welton NJ, et al. Inequalities in rates of renal replacement therapy in England: does it matter who you are or where you live? Nephrol Dial Transplant 2012;**27**(4):1598-607.

48. Moist LM, Bragg-Gresham JL, Pisoni RL, et al. Travel time to dialysis as a predictor of health-related quality of life, adherence, and mortality: the Dialysis Outcomes and Practice Patterns Study (DOPPS). Am J Kidney Dis 2008;**51**(4):641-50.

49. Cho Y, Badve SV, Hawley CM, et al. The effects of living distantly from peritoneal dialysis units on peritonitis risk, microbiology, treatment and outcomes: a multi-centre registry study. Bmc Nephrology 2012;**13**.

50. Bello AK, Wiebe N, Hemmelgarn BR, et al. A population-based study on care and clinical outcomes in remote dwellers with heavy proteinuria. Kidney International Supplements 2013;**3**(2):254-58.

51. Thompson S, Bello A, Wiebe N, et al. Quality-of-care indicators among remote-dwelling hemodialysis patients: a cohort study. Am J Kidney Dis 2013;**62**(2):295-303.

52. Miller LM, Vercaigne LM, Moist L, et al. The association between geographic proximity to a dialysis facility and use of dialysis catheters. Bmc Nephrology 2014;**15**.

53. Tonelli M, Hemmelgarn B, Culleton B, et al. Mortality of Canadians treated by peritoneal dialysis in remote locations. Kidney Int 2007;**72**(8):1023-8.

54. Tonelli M, Manns B, Culleton B, et al. Association between proximity to the attending nephrologist and mortality among patients receiving hemodialysis. Cmaj 2007;**177**(9):1039-44.

55. Littenberg B, Strauss K, MacLean CD, et al. The use of insulin declines as patients live farther from their source of care: results of a survey of adults with type 2 diabetes. BMC Public Health 2006;**6**:198.

56. Strauss K, MacLean C, Troy A, et al. Driving distance as a barrier to glycemic control in diabetes. J Gen Intern Med 2006;**21**(4):378-80.

57. Zgibor J, Gieraltowski L, Tallbot E, et al. The association between driving distance and glycemic control in rural areas. Journal Diabetes Science and Technology 2011;**5**(3):494-500.

58. Redhage LD, Harms K, Moore DE, et al. Closer proximity to the transplant center is associated with better physical health-related quality of life after liver transplantation. Hpb 2013;**15**:65-66.

59. Goldberg DS, French B, Forde KA, et al. Association of distance from a transplant center with access to waitlist placement, receipt of liver transplantation, and survival among US veterans. Jama 2014;**311**(12):1234-43.

60. Zorzi D, Rastellini C, Freeman DH, et al. Increase in mortality rate of liver transplant candidates residing in specific geographic areas: analysis of UNOS data. Am J Transplant 2012;**12**(8):2188-97.

61. Thabut G, Munson J, Haynes K, et al. Geographic Disparities in Access to Lung Transplantation Before and After Implementation of the Lung Allocation Score. Am J Transplant 2012;**12**(11):3085-93.

62. Lake IR, Jones NR, Bradshaw L, et al. Effects of distance to treatment centre and case load upon tuberculosis treatment completion. Eur Respir J 2011;**38**(5):1223-5.

63. Lara MD, Baker MT, Larson CJ, et al. Travel distance, age, and sex as factors in follow-up visit compliance in the post-gastric bypass population. Surg 2005;**1**(1):17-21.

64. Jennings N, Boyle M, Mahawar K, et al. The relationship of distance from the surgical centre on attendance and weight loss after laparoscopic gastric bypass surgery in the United Kingdom. Clinical Obesity 2013;**3**(6):180-84.

65. Sivagnanam P, Rhodes M. The importance of follow-up and distance from centre in weight loss after laparoscopic adjustable gastric banding. Surgical Endoscopy and Other Interventional Techniques 2010;**24**(10):2432-38.

66. Jones AP, Bentham G, Horwell C. Health service accessibility and deaths from asthma. Int J Epidemiol 1999;**28**(1):101-5.

67. McCarthy JF, Blow FC, Valenstein M, et al. Veterans Affairs Health System and mental health treatment retention among patients with serious mental illness: evaluating accessibility and availability barriers. Health Serv Res 2007;**42**(3 Pt 1):1042-60.

68. Joseph AE, Boeckh JL. Locational variation in mental health care utilization dependent upon diagnosis: A Canadian example. Social Science and Medicine - Part D Medical Geography 1981;**15**(3):395-404.

69. Skarsvag K, Wynn R. Travel Time and the Use of Psychiatric Outpatient Clinic Services in Coastal Northern Norway [4]. Canadian Journal of Psychiatry 2004;**49**(2):153-54.

70. Prue DM, Keane TM, Cornell JE, et al. An analysis of distance variables that affect aftercare attendance. Community Ment Health J 1979;**15**(2):149-54.

71. Monnet E. Socioeconomic context, distance to primary care and detection of hepatitis C: a French population-based study.

72. Jackson KL, Glasgow RE, Mone MC, et al. Does travel distance influence length of stay in elective pancreatic surgery? Hpb 2014;**16**(6):543-49.

73. Jackson KL, Glasgow RE, Hill BR, et al. Does Travel Distance Influence Length of Stay in Elective Colorectal Surgery? Dis Colon Rectum 2013;**56**(3):367-73.

74. Haynes R, Bentham G, Lovett A, et al. Effects of distances to hospital and GP surgery on hospital inpatient episodes, controlling for needs and provision. Soc Sci Med 1999;**49**(3):425-33.

75. Arcury TA, Preisser JS, Gesler WM, et al. Access to transportation and health care utilization in a rural region. J Rural Health 2005;**21**(1):31-8.

76. Ballard DJ, Bryant SC, O'Brien PC, et al. Referral selection bias in the Medicare hospital mortality prediction model: are centers of referral for Medicare beneficiaries necessarily centers of excellence? Health Serv Res 1994;**28**(6):771-84.

77. Etzioni DA, Fowl R, Wasif N. Distance Bias and Surgical Outcomes. Med Care 2013;**51**:238-44.

78. Lipe BC, Lansigan F, Gui J, et al. Bone marrow transplant for multiple myeloma: impact of distance from the transplant center. Clin 2012;**10**(1):28-32.

79. Wasif N, Pockaj BA, Gray RJ, et al. Distance travelled is an unrecognized bias for short and longterm outcomes following complex gastrointestinal cancer surgery: Results from the national cancer database. Ann Surg Oncol 2014;**1)**:S28.

80. Lenhard Jr RE, Enterline JP, Crowley J, et al. The effects of distance from primary treatment centers on survival among patients with multiple myeloma. Journal of clinical oncology : official journal of the American Society of Clinical Oncology 1987;**5**(10):1640-45.

81. Lamont EB, Hayreh D, Pickett KE, et al. Is patient travel distance associated with survival on phase II clinical trials in oncology? J Natl Cancer Inst 2003;**95**(18):1370-75.

82. DeNino WF, Osler T, Evans EG, et al. Travel distance as factor in follow-up visit compliance in postlaparoscopic adjustable gastric banding population. Surg 2010;**6**(6):597-600.

83. Gunderson CC, Nugent EK, McMeekin DS, et al. Distance traveled for treatment of cervical cancer: who travels the farthest, and does it impact outcome? Int J Gynecol Cancer 2013;**23**(6):1099-103.

84. Celaya MO, Berke EM, Onega TL, et al. Breast cancer stage at diagnosis and geographic access to mammography screening (New Hampshire, 1998-2004). Rural Remote Health 2010;**10**(2):1361.

85. Meersman SC, Breen N, Pickle LW, et al. Access to mammography screening in a large urban population: a multi-level analysis. Cancer Causes Control 2009;**20**(8):1469-82.

86. Heelan K, McKenna D. Distance to specialist services and relationship to Breslow thickness at presentation of patients with malignant melanoma. J Am Acad Dermatol 2011;**1)**:AB118.

87. Henry KA, Sherman R, Farber S, et al. The joint effects of census tract poverty and geographic access on late-stage breast cancer diagnosis in 10 US States. Health Place 2013;**21**:110-21.

88. Schroen A, Lohr M. Travel Distance to Mammography and the Early Detection of Breast Cancer. The Breast Journal 2009;**15**(2):216-17.

89. Crawford SM, Sauerzapf V, Haynes R, et al. Social and geographical factors affecting access to treatment of colorectal cancer: a cancer registry study. Bmj Open 2012;**2**(2).

90. Cosford P, Garrett C, Turner K. Travel times and radiotherapy uptake in two English counties. Public Health 1997;**111**(1):47-50.

91. Henry K, Boscoe FP, Johnson C, et al. Breast cancer stage at diagnosis: is travel time important? J Community Health 2011;**36**(6):933-42.

92. Sauerzapf V, Jones A, Haynes R, et al. Travel time to radiotherapy and uptake of breast-conserving surgery for early stage cancer in Northern England. Health Place 2008;**14**(3):424-33.

93. Swan-Kremeier LA, Mitchell JE, Twardowski T, et al. Travel distance and attrition in outpatient eating disorders treatment. Int J Eat Disord 2005;**38**(4):367-70.

94. Markin CJ, Roessel LL, Lai GP, et al. Does geographic distance from a pulmonary hypertension center delay diagnosis and treatment? A REVEAL registry analysis. Journal of Heart and Lung Transplantation 2011;**1)**:S14.

95. Stoller JK, Sandhaus RA, Turino G, et al. Delay in diagnosis of alpha1-antitrypsin deficiency: A continuing problem. Chest 2005;**128**(4):1989-94.

96. Rodkey SM, Hobbs RE, Goormastic M, et al. Does distance between home and transplantation center adversely affect patient outcomes after heart transplantation? Journal of Heart and Lung Transplantation 1997;**16**(5):496-503.

97. Ragon BK, Clifton C, Chen H, et al. Geographic Distance Is Not Associated with Inferior Outcome When Using Long-Term Transplant Clinic Strategy. Biology of Blood and Marrow Transplantation 2014;**20**(1):53-57.

98. Firozvi AA, Lee CH, Hayashi PH. Greater travel time to a liver transplant center does not adversely affect clinical outcomes. Liver Transpl 2008;**14**(1):18-24.

99. Tonelli M, Klarenbach S, Manns B, et al. Residence location and likelihood of kidney transplantation. Can Med Assoc J 2006;**175**(5):478-82.

100. Leese GP, Feng Z, Leese RM, et al. Impact of health-care accessibility and social deprivation on diabetes related foot disease. Diabet Med 2013;**30**(4):484-90.

Supplementary Material 1: Medline Search Strategy

Intervention/ Comparator terms	Population accessing Healthcare	Health Outcomes
Proximity adj3 health*.ti,ab	health*adj3 access*.ti,ab	Health status.ab,ti
Proximity adj3 hospital*.ti,ab	health* adj3 care.ti,ab	Health inequal*.ab,ti
Travel*.ab,ti	health* adj3 facilit*.ti,ab	"health related quality of life".ab,ti
Distance*.ab,ti	hospital*.ti,ab	Hrqol.ab,ti
Patient adj3 transport.ti,ab	inpatient*.ab,ti	Mortality.ab,ti
Journey*adj5 (car or bus or transit or transport* or public transport or train).ti,ab	outpatient*.ti.ab	Delay* adj3 diagnosis.ab,ti
Time to hospital*.ab,ti	health* adj3 appoint*.ab,ti	Late* adj3 diagnosis.ab,ti
Transportation of patients/	rural adj3 health*.ab.ti	Miss*adj3 appoint*.ab,ti
Travel/	urban adj3 health*.ab,ti	Health adj3 outcome.ab,ti
-	communit* adj3 health*.ti,ab	Quality of life.ab,ti
	primary health*.ab,ti	Self reported health.ab,ti
	family practice.ab,ti	Prognosis.ab,ti
	gen* pract*.ab,ti	Complete adj3 treatment.ab,ti
	health* adj3 screen*.ti,ab	Did not attend.ab,ti
	clinic.ab,ti or clinics.ab,ti	Health status/ or health status disparities/
	GP.ab,ti	*"Quality of life"/ or patient compliance/ or patient refusal/ or diagnosis/ or delayed diagnosis/
	"accident and emergency".ab,ti	Mortality/
	health services accessibility/	Prognosis/

	hospitals/ or hospitals, community/ or hospitals, general/ or hospitals, group practice/ or hospitals, high-volume/ or hospitals, low-volume/ or hospitals, private/ or hospitals, public/ or hospitals, rural/ or hospitals, satellite/ or hospitals, special/ or hospitals, teaching/ or hospitals, urban/ or mobile health units/ or secondary care centers/ or tertiary care centers/Appointments and schedules/	Treatment adj3 retention.ab,ti
	Mass screening/	Treatment adj3 follow adj3 up.ab,ti
	Urban health/	Patient complian*.ab,ti
	Rural health/	
	Health services/ or primary healthcare/ or general practice/ or tertiary healthcare/	
	Emergency service, hospital/	

Restrictions	NOT exercise test/ or exercise test.ab,ti
	English Language

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5-6
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	2 & 4
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4 & 5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Supplementary Material 1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5/6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5/6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Tables 1-4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	Table 1 and page 7
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	n/a
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Meta analysis not appropriate.

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	Table 1 (p6)
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Figure 1 page 7
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Tables 2 – 4 (p8 – 32)
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Summarised across studies – see #22 below
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	N/A
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	N/A
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	Table 1 p6
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	P35 - 38
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	P38& 3
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	P38
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	P39

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

BMJ Open

Are differences in travel time or distance to healthcare for adults in global north countries associated with an impact on health outcomes? A systematic review

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Are differences in travel time or distance to healthcare for adults in global north countries associated with an impact on health outcomes? A systematic review

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ABSTRACT

Objectives: To investigate whether there is an association between differences in travel time/ travel distance to healthcare services and patients' health outcomes and assimilate the methodologies used to measure this.

Design: Systematic Review. We searched MEDLINE, Embase, Web of Science, Transport database, HMIC, and EBM-Reviews for studies up to 7th September 2016. Studies were excluded that included children (including maternity), emergency medical travel, or countries classed as being in the global south.

Settings: A wide range of settings within primary and secondary care (these were not restricted in the search)

Results: One hundred and eight studies met the inclusion criteria. The results were mixed. Seventy seven percent of the included studies identified evidence of a distance decay association, whereby patients living further away from healthcare facilities they needed to attend had worse health outcomes (e.g. survival rates, length of stay in hospital, non-attendance at follow-up) than those that lived closer. Six of the studies identified the reverse (a distance bias effect) whereby patients living at a greater distance had better health outcomes. The remaining 19 studies found no relationship. There was a large variation in the data available to the studies on the patients' geographical locations and the healthcare facilities attended and the methods used to calculate travel times and distances were not consistent across studies.

Conclusions: The review observed that a relationship between travelling further and having worse health outcomes cannot be ruled out and should be considered within the healthcare services location debate.

PROSPERO number: CRD42014015162

Strengths and Limitations of this research

- This systematic review has for the first time synthesized available evidence on the association between differences in travel time/distance to healthcare services and patients' health outcomes.
- It has identified a wealth of studies and generated evidence for wide range of disease groups and health outcomes, across multiple countries.
- The review found great variation in study design, distances and travel time to access healthcare settings, and range of health outcomes; this precluded pooling of data for a meta-analysis.
- While the review findings are of undoubted value in broadening our understanding of the wider societal factors that influence health outcomes, their applicability may be limited to countries with similar healthcare systems.

INTRODUCTION

Countries such as the UK, USA and Canada have been implementing a policy of centralising the care of patients for many specialised services. There is evidence that this process will have a positive impact on the health outcomes of those patients treated in these specialised centres ([1], [2]). However, there are also drawbacks to increasing the distance some patients travel to receive treatment. A number of authors have documented the *distance decay* association, which identifies that those that live closer to healthcare facilities have higher rates of utilisation after adjustment for need than those who live further away ([3 4]). Indeed as long ago as 1850 Jarvis proposed this distance decay effect by finding that fewer patients were admitted to a mental hospital in Massachusetts the further they lived from that hospital [5]. Whilst there is evidence of this distance decay association there is less evidence on how this translates into impacts on health outcomes. Having to travel further to access healthcare facilities and the impact this has on patients health requires further investigation.

A growing number of studies have determined transport accessibility levels to healthcare using Geographical Information Systems (GIS) techniques, by mapping car and public transport travel times and distances to healthcare facilities. These can be broadly split into *revealed accessibility and potential accessibility methods, as defined by Khan.* [6]. *Revealed accessibility refers to methods that utilise data from actual healthcare trips. For example the drive time or straight-line distance between a patients' home address and the hospital they attended ([7], [8]). Potential accessibility refers to methods that look at what is the potential for accessing healthcare facilities in a particular area. For example using gravity models ([9]) and specialised gravity models - 2 step flotation catchments areas method ([10], [11]).* Whilst these methods are being widely used and developed the link between transport accessibility to healthcare and the association of this with patients' health outcomes has not frequently been considered (in part due to a lack of linked health and transport accessibility data). The aim of this review is to bring together studies that have calculated revealed accessibility (patients travel to healthcare facilities – ex post) and explored whether there is an associated impact from this on health outcomes. The focus lies on whether there is an association and the data and methods used.

METHODOLOGY

The review protocol was published in advance on the PROSPERO database (CRD42014015162). The study followed the PICOS (Population, Intervention, Comparator, Outcome, Study type) search design[12]. The population were adults accessing healthcare in global north countries (studies were included from the following regions/ countries: Northern America, Western Europe, Australia and New Zealand). The intervention and comparator were the distance and travel times to healthcare. The outcomes were any health outcomes (e.g. survival, mortality, quality of life) and proxy measures for health outcomes (e.g. follow up attendance, utilisation of clinic). No restriction was made on study type or design. We searched Web of Science, MEDLINE, Embase, Transport database, HMIC, and EBM Reviews for relevant papers in November 2014 and updated the search on 7th September 2016. The MEDLINE search strategy is accessible in supplementary material 1. All titles and abstracts were screened by CK and 20% independently by CH. The key inclusion criteria were that the study quantified distance or travel time to healthcare AND identified whether there was an impact from this on health outcomes AND the assessment of travel time/ distance on the health outcome was the primary objective of the study.

The study excluded papers:

- Including children (< 18 years old and maternity).
- Reporting only patient opinions and views.
- Reporting only one off emergency events or travel by different types of emergency vehicles including Myocardial Infarction and transfers between healthcare facilities.
- Reporting only countries classed as global south.

The full papers of studies that met the inclusion criteria were reviewed by CK and CH and data extraction and quality assessment was completed. Reference lists of included papers were then reviewed to identify any additional studies. These were subjected to the same review process described above. The quality assessment of the studies was undertaken using a modified version of the cohort studies Critical Appraisal Skills Programme (CASP) tool [13] linked to the PICO terms. It included key components of the CASP tool for example; did the study address a clearly defined question? Had a representative population been used? Was the exposure (distance or travel time) accurately measured to minimise bias? And the same for the health outcome; whether potentially confounding variables had been identified and included in the analysis. In addition we included whether the funding source was external to the organisation and whether the study was peer reviewed. This was important as studies completed in-house may have an inherent tendency to be biased. The data was extracted and assessed for quality by CK, according to the study protocol and 20% independently extracted and assessed by CH. No studies were excluded on the basis of the quality assessment.

RESULTS

One hundred and eight studies met the inclusion criteria and were included in the review. The study flow diagram is provided in Figure 1, which shows that over 13,000 abstracts were initially reviewed. The studies covered a wide range of diseases, interventions and health outcomes. The results of the quality assessment are summarised in table 1. The main area of concern was the funding source of the study – 37% of the studies were funded in-house or it was unclear how they were funded, which may lead to bias. However, no studies were excluded on the basis of this assessment.

We have categorised the studies according to the following 3 groups:

1. *Distance Decay Association* – Studies that showed evidence of an association between patients living closer to the healthcare facility and having better health outcomes/ higher access rates to the healthcare services compared to those living further away (see table 2).

2. *Distance Bias Association* – Studies that showed evidence of an association between patients living further away from the healthcare facility and having better health outcomes/ higher access rates to the healthcare services compared to those living closer to the healthcare facilities (see table 3).

3. *No Association* – Those studies that found no evidence of an association between distance from the health facility and health outcome (see table 4).

Seventy seven percent of the included studies identified a distance decay association; six studies reported a distance bias association and 19 identified no relationship.

Table 1 Quality Assessment of Studies n (%)

	Yes	No	Unclear/Partial
Did the study address a clearly focused question?	108 (100%)	0	0
Was the study population recruited in an acceptable way?	105 (97.2%)	0	3 (2.8%)
Did it include all the population or describe the population not included?	97 (89.8%)	7 (6.5%)	4 (3.7%)
Was the method used to calculate the distance/ travel time reported accurately?	85 (81.5%)	23 (18.5%)	0
Was the health outcome accurately measured to minimise bias?	108 (100%)	0	0
Have important confounding factors been taken account of in the design or analysis?	90 (83.3%)	17 (15.7%)	1 (1%)
Is the funding source external to the organisation?	68 (63.0%)	16 (14.8%)	24 (22.2%)
Was the research peer reviewed?	101 (93.5%)	0	7 (6.5%)

Figure 1

Table 2: Included studies that identified evidence of a distance bias association

Author Country Date	Disease / Procedure	Source, Years & Sample size	Health Outcome	Distance/ travel time measurement	Origin and Destination	Summary of key results
Cancer Studies						
Abou-Nassar, et al. [14] USA 2012	Allogeneic Hematopoietic Stem Cell Transplantation	Clinical Operations and Research Information Systems database at DF/BWCC. 1996 - 2009. Sample = 1,912 (meeting the criteria of living < 6 hours to the treatment centre).	Overall Survival	Travel Time. Calculated using driving distance and average driving speeds along the road network Travel time was treated as a categorical variable using 3 groups: ≤40, 41 - 159, ≥160 mins and also a continuous variable. The range of distances was 2 - 358 mins.	Patients' Residence TO The transplant Centre	The study found that longer drive times to the transplant centres was associated with worse overall survival in patients alive and disease free after 1 year - This was only true using travel time as a continuous variable. They suggest this may be in part related to the lower number of visits in patients living further away after receiving the transplant.
Albornoz et al. [15] USA 2015	Breast Reconstruction	National Cancer Database Included Patients who had a unilateral or bilateral mastectomy with or without reconstruction 1998 – 2011 1,031,343	The rate and method of breast reconstruction services	Straight-line Distance Straight-line distance. Using the "Great Circle Distance" in the database. Treated as a continuous variable. For 2011 the average distance travelled for mastectomy without reconstruction – 27.1 miles and 34 miles with reconstruction.	Patients' Residence (zip code or city if zip code was unavailable) TO Hospital that reported the case.	The study found that patents had travelled further for breast reconstruction services than for mastectomy without reconstruction. Indicating a distance bias. Patients were more likely to have immediate breast reconstruction the further they had travelled (0-20 miles 13.9% reconstruction 101-201 24.9%).
Anderson, et al. [16] USA 2013	Colorectal Cancer	A set of cross sectional telephone survey of the population > 18 years in the USA. Taken from the Utah Behaviour Risk Factor Surveillance System. 2010	Adherence to risk appropriate screening guidelines	Travel Time The study calculated 1 mile grid cells for the state of Utah and for each grid cell populated with individuals aged 50 or older they calculated the actual travel time to the nearest colonoscopy provider. This was then used to	Patients' residence (determined using a 1 mile grid reference for the addresses) TO The nearest colonoscopy provider.	The study found that residents living > 20 mins from the nearest colonoscopy provider were significantly less likely to be up-to-date with risk appropriate screening than those living < 10 mins from the nearest provider.

		Sample = 2,844		calculate a population weighted median travel time by zip code. Travel times was treated as a categorical variable and grouped into 3 categories: <10 minutes, 10 - 20 minutes & >20 minutes.		
Athas, et al. [17] USA 1999	Breast Cancer	New Mexico Tumour Registry & The National Cancer Institute's surveillance Epidemiology and End Results. Patient Diagnosed 1994 – 1995 Sample = 1,122	Receipt of radiotherapy following breast conserving surgery	Straight-Line Distance. Distance was treated as a categorical variable and split into the following categories: <10 miles, 10.0-24.9, 25.0-49.9, 50.0-74.9, 75.0-99.9, ≥100 miles.	Patients' Residence (street address (70% of cases) and centroid of residential zip codes (30%)). TO The nearest radiation treatment facility.	The study found that by controlling for age the likelihood of receiving radiotherapy following breast conserving surgery decreased significantly with increasing travel distance to the nearest facility. This was significant for distances >74.9miles compared to a base of <10miles.
Baade, et al. [18] AUSTRALIA 2011	Rectal Cancer	Queensland Cancer Registry (QCR) 1996 - 2007 Sample = 6,848	Cause specific survival	Road Distance and Travel Times. The distances were treated as a categorical variable using the following groups: < 50km, 50 - 99km, 100 - 199, 200 – 399 and ≥400km. The travel times were treated as a categorical variable using the categories of 0 -1hours, 2-4, 4-6, ≥ 6 hours	Patients' Residence TO The nearest radiotherapy facility	The study found that after adjusting for age, sex and stage at diagnosis, patients who lived 100 - 199km, 200-399km and 400km or more from a radiotherapy facility were 16%, 30% and 25% respectively more likely to die from cancer than patients living within 50km of such a facility. For every 100km increase in distance there was on average a 6% increase in risk of mortality. Similar results were found when travel time was used in the calculations, where patients living greater than 6 hours away were 22% more likely to die from cancer than those living 0- 1 hours away.
Brewer, et al. [19] NEW ZEALAND 2012	Cervical Cancer	New Zealand Cancer Registry. 1994 - 2005 Sample = 1,383	Cancer screening, stage at diagnosis and mortality	Travel Time and Road distance. The distances and travel times were treated as categorical variables using the following method of grouping - low - the lowest quartile, Medium - quartiles 2 and 3, High - records between the 75th and 95th percentiles and Highest - the highest 5% of records.	The 2001 census area unit for the patient (population weighted centroid) TO The nearest GP and nearest Cancer Centre	The study found that increased travel time/ distance was weakly associated with cervical cancer screening, stage at diagnosis and mortality.

Bristow, et al. [20] USA 2014	Ovarian Cancer	Californian Cancer Registry 1996 - 2006 Sample = 11,770	Treatment Adherence	Distance. (Does not say what method used) calculated using ESRI ArcMAP Distance was treated as a categorical variable and split into quintiles from < 5km up to > 80km.	Patients' Residence TO The treating hospital and the closest high volume hospital.	The study found that living > 80km (compared to < 9km) from a high volume hospital was associated with an increased risk of non-adherence to care plans (OR = 1.88, Confidence interval, 1.61 - 2.10). The study found that distance to a high volume hospital and distance to receive treatment could be used to predict whether patients would meet the guidelines for care for advanced stage ovarian cancer.
Burmeister, et al. [21] AUSTRALIA 2010	Lung Cancer	Queensland Cancer Registry. 2000 - 2004 Sample = 1,535	Delay in receiving radiation therapy Survival	Road Distance. (no info on GIS methods used) Distance was treated as a categorical variable using the groups of < 50km (where it was assumed that patients could travel on a daily basis from home) 50 - 200km (where it was assumed patients would go home for weekends only) and > 200km (where it was assumed that patients would need to spend the duration of their treatment at the hospital).	Patients' Residence (postcode) TO The nearest public radiation treatment facility.	The study found that waiting times for radiation therapy among lung cancer patients in Queensland was not associated with distance from home to the nearest public radiation treatment facility. The study did find that those living > 200km away had slightly worse survival than those who lived < 50km.
Campbell, et al. [22] UK 2001	Colorectal and Lung Cancer	Scottish Cancer Registry 1995 - 1996 Sample = 1,323	Presence of disseminated disease at diagnosis & emergency presentation or surgery.	Straight-line Distance. Distance was treated as a categorical variable using the groups of 0 - 5km, 6 - 37km, 38 - 57km and ≥58km. These were pre-defined cut off points.	Patients' Residence - (Census output area centroids) TO The nearest cancer centre.	The study identified that increasing distance from the nearest cancer centre was associated with a higher chance of disseminated disease at diagnosis and therefore lower chances of survival.
Campbell, et al. [23] UK 2000	Cancer (Lung, Colorectal, Breast, Stomach, Prostate, Ovary)	Scottish Cancer Registry 1991 - 1995 Sample = 63,976	One Year Survival	Straight-line Distance. Distance was treated as a categorical variable using the groups ≤ 5km, 6 - 13km, 14 - 23km, 24-37km and ≥38km.	Patients' Residence (postcode) TO The nearest cancer centre	The study found that increasing distance from the nearest cancer centre was associated with a reduced chance of diagnosis before death for stomach, breast and colorectal cancer and poorer survival after diagnosis for prostate and lung cancer.

Celaya, et al. [24] USA 2006	Breast Cancer	New Hampshire State Cancer Registry. 1998 - 2001. Sample = 2,861	Type of treatment received - either breast conserving surgery with radiography or Mastectomy	Straight-line Distance. Distances were treated as categorical variable using the groups <20 miles, 20 to <40, 40 to < 60, ≥60 miles. The mean distance was 15.1 miles (range 0.1–89.9).	Patients Residence (Residential Address geocoded (80%) or zip code centroid (20%)) TO The nearest radiation treatment facility.	The study found that women were less likely to have breast conserving surgery with increasing distance from the nearest facility. Women were less likely to have radiation therapy the further away they lived - if they had previously undergone breast conserving surgery.
Cramb, et al. [25] AUSTRALIA 2012	Breast Cancer and colorectal cancer	Queensland Cancer Registry. 1996 - 2007 Sample = 26,390 Males = 14,690 and Females = 11,700	Survival and premature deaths	Travel Time. Shortest travelling time by road. Travel time was grouped into 3 categories based on practical considerations. < 2hours, 2 - 6 hours and >6 hours	Centroid of the patients' statistical local area TO The closest radiation facility	The study concluded that the proportion of premature deaths was higher for those living >2 hours from a treatment facility for breast cancer. Colorectal patients living > 6 hours from a treatment facility had poorer outcomes than those in the 2- 6 hour category, but this was not statistically significant.
Crawford et al. [26] UK 2009	Lung Cancer	Northern and Yorkshire Cancer Registry and Information Service. 1994 - 2002 Sample = 34,923	Diagnosis and form of treatment	Travel Time. Calculated using ArcGIS 9.2 using average car speeds along the shortest route. Travel time was treated as a categorical variable - dividing the patients into equal quartiles. Patients were then put into 1/ 16 groups that combined 4 quartiles of travel time and 4 quartiles of deprivation.	Patients' Residence TO The closest hospital providing diagnostic access.	The study found that patients living in the most deprived areas were least likely to receive histological diagnosis, active treatment and thoracic surgery. They found that travel time "amplified this effect "– patients in the most distant & most deprived group had the worst outcomes.
Dejardin, et al. [27] FRANCE & ENGLAND 2014	Colorectal cancer	3 Cancer registries (Calvados, Cote d'Or and Saone et Loire) and 1 cancer registry in England (Northern and Yorkshire). 1997 - 2004 Sample = 40,613	Survival	Travel Time. Using ArcGIS in England and Mapinfo in France. The study used road map databases using legal speed limits by road class. Travel time was treated as a categorical variable using the 5 groups of 0 - 5 mins, 6 - 20 mins, 21 - 40mins , 41 - 90 mins and ≥ 91mins for travel times to the	Patients' Residence (at the time of diagnosis) TO The nearest cancer centre, radiotherapy centre and hospital.	The study identified (unadjusted analysis) that travel times were significantly associated with survival, as patients living further from healthcare resources had a better chance of survival than those living closer. When including material deprivation in the model this effect was removed.

				nearest cancer centre & nearest radiotherapy unit and 0 - 5, 6 - 10, 11-15, 16 - 40 and ≥41mins for travel to the nearest hospital.		
Dupont-Lucas, et al. [28] FRANCE 2011	Colorectal Cancer	Clinical trials in Calvados Normandy and Cote-d'Or Burgundy - testing the diagnostic properties of two types of faecal occult blood test. June 2004 - December 2006 Sample = 4,131	Colonoscopy uptake	Road Distances. Calculated using Mapinfo 9.1 combined with CHRONOMAP 2.1 based on the MultiNet Map database (Tele Atlas). Distances were grouped into quartiles: 0 - 5.5km, 5.5 - 13.8, 13.8 - 22.1 & 22.1 - 52.3km.	Patients' Residence (Home Address) TO The nearest gastroenterologist / or regional capital /or clinical trial centre	The study found that distance to the regional capital and distance to the clinical trial centre were independently associated with colonoscopy uptake. Distance to the nearest gastroenterologist was not found to be significant.
Engelman, et al. [29] USA 2002	Breast Cancer	The Health Care Financing Administration enrolment database to identify each fee for service Medicare eligible women in Kansas. - Medicare Claims data. 1997 - 1998 Sample = 117,901	Mammogram attendance	Straight-Line Distance. Distance was treated as a continuous variable.	Patients' Residence (zip code) TO The nearest permanent & mobile mammography sites.	The study showed that increasing distance from a permanent mammogram facility was significantly associated with decreased mammogram rates. After controlling for age, race and education this relationship was still significant. OR = 0.97 for each 5 mile increment.
Fournel, et al. [30] FRANCE 2010	Colorectal Cancer	Burgundy Registry. 1990 - 1999. Sample = 6220 colorectal adenoma patients and 2,387 colorectal cancer patients.	Colorectal adenoma detection	Distance. (method not reported) Distance were included as a categorical variable using groupings of <5km, 5 - 15km and >15km.	Patients' Residence TO The GP, hepatogastroenterologist (HGE), and physician (not clear whether these were the nearest)	The study found that incidences of colorectal cancer were not significantly associated with distance to the GP, HGE, or the physician. The study did find a significant interaction between place of residence and the distance to the GP and place of residence and the HGE. The impact of the distance to the physicians was significant for patients living in rural areas.
Giuliani et al. [31] Italy	Breast Cancer	Romagna Cancer Registry Patients were included	Compliance with yearly mammography and /or Clinical	Travel Times. Calculated using Google Maps. Travel time was split into	Patients' Residence (assumed not stated) TO	The study found that patients were less likely to have a yearly check-up (over the 10 years) if they had to travel >30 mins compared to ≤15 mins.

2016		if they had a diagnosis of in situ and invasive cancer between 1990 – 2000 735	breast examination over 10 year follow up period.	categories ≤15 mins, 16 – 30 and >30. The study also considered the altitude of the patient's residence.	The centre for cancer prevention	
Goyal et al. [32] USA 2015	Breast Cancer	Breast Cancer Disparity Cohort Study (New Jersey) African American and white patients diagnosed with early stage breast cancer. 2005 - 2011 623	Mastectomy OR Breast conserving surgery followed by adjuvant radiation therapy	Travel Distance and Travel Time Shortest travel time/ distance was calculated using Google Maps. Distance and travel times were treated as categorical variables and split up into quartiles. Travel distance <3.2miles, 3.2-5.6, 5.7-9.2 and >9.2miles. Travel times <9 mins, 9-13 mins, 14-19 mins and >19 mins.	Patients' Residence TO The radiation facility where patients received Radiation Therapy (where unavailable-surgeons were contacted by phone and the referral obtained)	The study found that patients living further away from the radiation therapy centre in the categories of 5.7-9.2miles and >9.2miles compared to < 3.2 miles (REF) were significantly more likely to have a mastectomy than breast conserving surgery followed by RT. Patients living > 19mins compared to <9 mins were also more likely to receive a mastectomy rather than breast conserving surgery.
Haddad et al. [33] USA 2015	Bladder Cancer	Urban tertiary cancer centre (single site) 2007 – 2013 406	Short and long term survival after radical cystectomy	Shortest Driving Distance Calculated using Google Maps Distance was treated as a categorical variable. Using the categories of < 50 miles, 50 – 100, 100.1 – 150 and >150 miles. Median distance 37.3miles	Patients' Residence TO The Treatment Facility (Single Site)	The study found that increasing distance to the facility was a significant predictor of 90 day mortality (univariate model) and was still significant after controlling for nodal status. For long term survival distance was significant for those travelling >150miles versus <50miles for the univariate model.

Haynes, et al. [34] New Zealand 2008	Cancer (prostate, colorectal, breast, lung, melanoma)	New Zealand Ministry of Health 1994 - 2006 Sample = 1,383	Late diagnosis and likelihood of death	Travel Time. Travel time was treated as a categorical variable and split into 4 categories (Low, medium, High, Highest) low - lowest quartile, medium (quartile 2 and 3) high records between 75% and 95 percentiles and highest - highest 5% of records. This grouping was used to account for the skewed travel times.	Population weighted centroid of the 2001 census area units (CAU represent approx. 2300 people) TO The nearest cancer centre and nearest GP	The study had mixed results. After controlling for the extent of the disease, poor survival was associated with longer travel times to the GP for prostate cancer and longer travel times to the nearest cancer centre for colorectal, breast and prostate cancers, but not lung cancer or melanoma The study found that the disease tended to be less advanced in patients who lived further from the cancer centres and living further from a GP practice was not associated with a later stage diagnosis.
Holmes, et al. [35] USA 2012	Prostate Cancer	Physician workforce study in North Carolina & North Carolina Central Cancer Registry on patients diagnosed with incident cancer linked to Medicare claims. 2004 - 2005 Sample = 2,251	Delayed Diagnosis	Straight-line Distance. Distance was treated as a categorical variable and used 3 groups of: 0 - 10 miles, 11 - 20miles and > 20 miles.	Patients' Residence (zip code centroid of patient residence) TO The nearest urologist	The study found that increasing distance to an urologist was significantly associated with higher risk of prostate cancer at diagnosis, which was higher for black patients.
Huang, et al. [36] USA 2009	Breast Cancer	Kentucky Cancer Registry. 1999 - 2003 Sample = 12,322	Diagnosis Stage	Road Distance. Distance was treated as a categorical variable using the groups - <5 miles, 5 - 9, 10 - 14 and ≥15 miles	Patients' Residence (78% were geocoded based on street address. 15% using the centroid of the 5 digit zip code and 7% using the 5 digit zip code + 2 or + 4 digits) TO The nearest mammogram centre	The study found that patients diagnosed with advanced stage diagnosis had longer average travel distances than early stage diagnosis. After controlling for age, race, insurance and education the odds of advanced diagnosis were significantly greater for women living ≥15 miles compared to those living <5 miles.

Jethwa, et al. [37] USA 2013	Breast Cancer	Hospital Records. 2007 Sample = 260 (women were excluded if they were non-white or had a previous cancer diagnosis)	Stage of breast cancer at diagnosis, survival	Distance. (Unknown calculation). Distance was treated as a categorical variable using the following groups: < 15 miles, 15 - 44 miles, 45 - 59 miles, and ≥60 miles.	Patients' Residence TO The treating hospital	The study found that the further the distance the more likely women were to be diagnosed at a later stage and the more likely women were to have a mastectomy. The study found no association between travel distance, age at diagnosis, receipt of radiotherapy, or 5-year survival.
Jones, et al. [38] UK 2008	Breast colorectal, lung, ovarian and prostate cancer	Northern and Yorkshire Cancer Registry and Information Service (NYCRIS) 1994 - 2002 Sample = 117,097	Survival (whether patients were alive or dead on 31st March 2005) and late stage diagnosis	Travel Times. Calculated using average car travel speeds by road class on the road network. Travel time was treated as a continuous variable. The study also determined: - whether patients were within 800m of an hourly bus service for rural patients. Straight-line distance to the nearest cancer centre, car journey to the closest railway station, travel time to the GP and first referral hospital.	Patients' Residence TO The GP, Hospital of first referral and closest cancer centre	The study found that late stage diagnosis was associated with increasing travel time to the GP for breast and colorectal cancer and risk of death was associated with increased travel time to the GP for prostate cancer. The study identified residential deprivation was significantly related to survival.
Jones, et al. [39] UK 2010	Cancer (Colorectal, ovary, breast, prostate)	Northern and Yorkshire Cancer Registry Information Service. 1994 - 2002. Sample = 3,536	Whether or not the diagnosis was made at death. (Diagnosis date = death date)	Road Distance and Travel time Estimated using average travel speeds over the road network. The study also calculated straight-line distance and assessed whether patients lived within 800m walking distance of an hourly weekday bus service & whether there was a local community transport scheme. Travel time to hospital was modelled as a categorical variable using quartiles.	Patients' Residence (postcode) TO The nearest healthcare provider postcode/ Nearest GP	The study found that the highest odds of being diagnosed at death were for those living in the least accessible quartile of travel time for the hospital, but this association was only statistically significant for colorectal and ovary cancer. The study found that living in the least accessible travel time quartile to the GP had the highest odds of being diagnosed at death, but was not statistically significance. Breast and prostate cancer patients living closer to a frequent bus service were significantly less likely to be diagnosed at death.

Jones, et al. [40] UK 2008	Breast, Colon, Rectum, Lung, Ovary and Prostate Cancer	Northern and Yorkshire Cancer Registry (NYCRIS) 1994 - 2002 Sample = 117,097	Patients receiving surgery, chemotherapy or radiotherapy	Travel Time. Travel time was modelled as a categorical variable and divided into quartiles.	Patients' Residence (home postcode) TO The nearest hospitals providing treatment.	The study identified an inverse relationship between travel time and treatment take up. Patients were less likely to receive radiotherapy the further they lived from the hospital. Lung cancer patients were less likely to receive surgery & Lung and rectal patients were less likely to receive chemotherapy.
Kerschbaumer, et al. [41] AUSTRIA 2012	Glioblastoma Multiforme (GBM) - malignant brain tumor	Medical Records 1990 - 2009 Sample = 208	Survival (Months)	Shortest Road Distance. Distance was treated as a continuous variable. Average distance was 75km (range 1 - 870km)	Patients' Residence (home address) TO The neuro oncological centre	The study found that distance to the neuro oncological centre had a significant effect on overall survival. Patients were less likely to be treated with chemotherapy following surgery the further the distance away they lived. The study found that when a new treatment was introduced that could be administered locally this removed this effect.
Kim, et al. [42] UK 2000	Colorectal cancer	South and West Cancer Intelligence unit. 1991 - 1995 Sample = 4,962	Survival	Straight-line Distance. Distance was treated as a categorical variable using the following groups - ≤10 km, > 10 to ≤ 20 km, > 20 to ≤ 30 km and > 30km.	Patients' Residence(postcode) TO The treating hospital	The study found that those travelling ≥ 30km from the treating hospital had significantly poorer survival, but that those living 20 - 30 km away appeared to be least at risk. Implying a U shape in terms of risk.
Lavergne, et al. [43] CANADA 2011	Palliative Radiotherapy (PRT)- Cancer	Oncology Patient Information System (Nova Scotia) 2000-2005 Sample = 13,494	PRT Treatment & Consultation	Travel Time. Calculated using "GIS" and average vehicle speeds by road type. Travel time was treated as a categorical variable using 4 categories: 0 - <30 mins, 30 - < 60 mins, 60 - < 120 mins and 120 - 214mins.	Patients' Residence (postcode at death) TO The nearest treatment centre	The study found that Palliative radiotherapy use declined with increasing travel time and community deprivation.
Lin et al. [44] USA 2015	Colon Cancer (stage III)	National Cancer Data Base Patients aged 18 – 80 who had a colectomy within 3 months of diagnosis and survived > 6months 2007 – 2010 34,694	Receipt of adjuvant chemotherapy within 90 days of a colectomy.	Road Distance Calculated using Google Maps. Distance was treated as a categorical variable using the following categories; 0 – 12.49miles, 12.5-49.9, 50-249, and ≥250miles. For patients flying in from outside the USA for treatment straight-line	Patients' residence at diagnosis (centroid of zip code) TO Reporting facility (90% had treatment in the reporting facility.	The study found that patients travelling in the further two categories 50 – 249miles and ≥250 miles had a lower likelihood of receiving chemotherapy than those travelling less than 12.5miles.

				distance was used. Average distance travelled to the oncologist was 12.5 miles.		
Maheswaran, et al. [45] UK 2006	Breast Cancer	Anonymised data April 1998 - March 2001 Sample = 34,868	Breast Screening Uptake	Road Distance. Distance was treated as a categorical variable and a continuous variable. Distances were grouped into 2 km bands. <2km, 2 to <4, 4 to <6, 6 to<8 and ≥8	Patients' Residence (postcode) TO The screening location that they were invited to attend.	The study found that when analysed as a continuous variable there was a small but significant decrease in uptake of breast cancer screening with increasing distance - adjusted odds ratio of 0.87 (95% CI -0.79 - 0.95) for a 10km increase in distance. The strongest effect on breast screening uptake was deprivation.
Meden, et al. [46] USA 2002	Breast Cancer	Medical Records. 1999 – 2000 Sample = 66	Difference in treatment technique – Modified Radical Mastectomy vs Breast Conserving Therapy	Distance. Unclear method. Likely to be straight-line. Distance was treated as a categorical variable. Distances were split into <45 miles and ≥45miles. Average distance was 61.6 miles (range 0 – 138 miles)	Patients' Residence TO The nearest radiation oncologist facility.	The study found that access to breast conserving surgery declined as travel distance increased. Patients living further away were more likely to have had a mastectomy.
Nattinger, et al. [47] USA 2001	Breast Cancer	National Cancer Institute - Surveillance, Epidemiology and End Results (SEER) Registry. 1991 - 1992. Sample = 17,729	Receiving Breast conserving surgery (BCS) OR receiving BCS with radiotherapy.	Straight-line Distance. Distance was treated as a categorical variable - using the groups of < 5miles, 5 to <10, 10 to < 15, 15 to < 20, 20 to <30, 30 to <40, ≥ 40 miles for receipt of BCS vs mastectomy and the groups of 0 to <10, 10 to <20, 20 to <30, 30 to <40 and ≥ 40 miles for receipt of radiotherapy among BCS patients.	Patients' Residence (Census tract) TO The nearest hospital with a radiotherapy facility (centroid of the zip code)	The study found a statistically significant decline in the likelihood of patients undergoing breast conserving surgery living ≥15 miles from a hospital with radiotherapy facilities when compared to those living < 5miles. They also found a statistically significant result for those patients living ≥ 40 miles having a reduced rate of radiotherapy following Breast conserving surgery.
Onitilo, et al. [48] USA 2014	Breast Cancer - Mammography Screening	Local Cancer Registry. 2002 - 2008. Sample = 1,421	Stage at diagnosis	Road Distance and Travel Time. Calculated using ESRI ArcGIS. Distances were treated as continuous & categorical variables Travel times were split into the categories of 0 - 5 mins, 5 - 15 mins, 15 - 30 mins, 30 - 60 mins, ≥ 60 mins.	Patients' Residence (street address for the patients (where available) /centroid of patients zip code where not) TO The nearest mammogram facility and the actual facility attended.	The study found that women who missed none of their 5 annual mammograms lived a median of 15 minutes from the nearest facility, whilst those who missed 5 /5 lived a median time of 27 minutes. The study found that patients living >30 miles to the closest facility were less likely to be screened for breast cancer in the winter months.

Panagopoulou, et al. [49] GREECE 2012	Breast Cancer	Hellenic Cooperative Oncology Group (clinical trials in 6 Greek cities) 1997 - 2005 Sample = 2,789 (women)	Survival	Road Distance and Travel Time. Distance was grouped into < 300km and ≥ 300km. Travel time was grouped into < 4 hours and 4+ hours. Additional tests using the following distance categories: <50, 50 - 149, 150 - 249, 250 - 349, 350+km.	Patients' Residence (98.7% of the sample using residential address, or the city centre of the city of residence, for the remaining 1.3% the weighted mean of available distances to each destination hospital) TO The treating hospital	The study found that travelling a distance >300km and travel time of 4 + hours were significantly associated with worse survival outcomes (HR = 1.37 & 1.34) base <300km and <4h respectively.
Punglia, et al. [50] USA 2006	Breast Cancer	The linked Surveillance, Epidemiology and End Results- Medicare (SEER) database. 1991 - 1999. Sample = 19,787	Receiving Radiation Treatment after a Mastectomy	Straight-line Distance. Distance was treated as a continuous and categorical variable. Using categories of <25, 25-50, 50-75 and 75+ miles. 5 patients living more than 900 miles away were excluded, as were patients in Hawaii. The median distance was 4.83 miles.	Patients' Residence TO The nearest radiation treatment facility.	The study found that increasing distance to the nearest radiation treatment facility was associated with a decreased likelihood of receiving radiation treatment therapy. For each extra 25 miles of travel was associated with declining odds of receiving radiation. The effect of distance showed as being stronger where patients were >75 years and those travelling 75+ miles compared to <25 miles.
Schroen, et al. [51] USA 2005	Breast Cancer	Virginia Cancer Registry. Patients diagnosed 1996 - 2000. Sample = 20,094	Mastectomy rates VS Breast conservation and radiation therapy	Straight-line Distance. Distance was modelled as a categorical using 10 miles, 10 - 25, > 25 - 50 and > 50 miles (range 0 - 84miles)	Patients' Residence (zip code) TO The nearest radiation therapy facility.	The study found a higher rate of mastectomy the further distance the patient lived from the nearest radiation therapy facility (after controlling for tumour size, year of diagnosis and age).
Scoggins et al. [52] USA 2012	Breast cancer Lung cancer Colorectal cancer	Washington State Cancer Registry Washing state Medicaid enrolled at time of diagnosis or within 6 months	Stage at diagnosis (local or regional/distant Likelihood of surgical treatment. Time to first surgical	Driving Time and Driving Distance Calculated using MapQuest (www.mapquest.com)	Patients' residence (9 digit zip code used where available) TO	The study found that later stage diagnosis for breast cancer was associated with increased driving time (but not lung or colorectal cancer). There were no significant effects between travel time and likelihood of surgical treatment. A significant result was found for the time to first treatment for colorectal patients where after controlling for socio demographic factors, year of diagnosis, and cancer stage for every 1 hour increase in drive time, time

		1997 – 2003 4,413	treatment (number of days since diagnosis)	Distance and travel time were treated as categorical variables. The distance categories were:	Patients general practice/ primary care provider	to treatment was delayed by 5.9 days. The study concluded that there was no evidence that drive time was a better predictor than driving distance.
Temkin et al. [53] USA 2015	Gynaecologic cancer	University of Maryland Medical Centre (single site) Nov 2009 – Dec 2011 152	Completion of recommended adjuvant therapy	Travel Time and Distance Calculated using the Google Maps. Treated as continuous variables. Distance range 0.3 – 12 miles. Travel time range 2 – 169 mins.	Patients' Residence (zip code) TO The hospital attended	The study found mixed results - 87% of the sample completed the therapy. 11 people did not complete and 8 died before completion. They found that those patients living <10 miles or >50 miles were less likely to complete treatment (13% of the sample). Those living further were more likely to die before completing, but also had higher comorbidities.
Thomas et al. [54] Ireland 2015	Colorectal Cancer	Irish National Cancer Registry Patients who were diagnosed and still alive. Oct 2007 – Sept 2009 1273 sent questionnaires, 496 returned	Quality of life following survival (measured using QLQ-30)	Distance Unspecified method Distance was treated as a categorical variable. Distances were divided into tertiles. Groups 1 and 2 were combined (≤30.81km) & group3 (>30.81km). Group 3 was then defined as living "remotely" from the hospital.	Patients Residence (at time of diagnosis) TO The hospital they were treated at.	The study assessed the impact of distance on the components to the QLQ-30. This was then split by gender. The study found that living a greater distance from the hospital was associated with – lower physical functioning and role functioning (for women and not men). For men living remotely (>30.8km) had a significant negative impact on their overall self-reported health and quality of life, but not for women.
Tracey et al. [55] Australia 2015	Lung Cancer	New South Wales Central Cancer Registry 2000 - 2008 11,457 (split into diagnosis – localised stage, regional and distance)	Survival (at one and five years)	Straight-line Distance Calculated using the 'Great Circle distance calculator' Distance was treated as a categorical variable using 3 groups of 0-39km, 40-99km and 100+ km.	Patients' Residence TO The nearest specialist public hospital (NASH) & nearest general hospital.	The study found that patients living further away from the specialist hospitals were less likely to attend the specialist hospital & less likely to have curative surgery – Resulting in lower survival rates. Patients who lived further away & were admitted to a specialist hospital and received curative surgery were more likely to survive at 5 years than those not receiving curative surgery.
Tracey et al. [56] Australia 2015	Lung Cancer (localised non-small cell)	NSW Central Cancer Registry Patients admitted with localised stage at diagnosis ≤12 months following diagnosis	Receiving Surgical resection within 12 months of diagnosis	Straight-line Distance Calculated using the 'Great Circle distance calculator' Distance was treated as a categorical variable using 3	Patients' Residence TO The nearest specialist public	The study found that 51% of patients living >100km from a specialist hospitals didn't have surgery compared to 38% of those living <40km. Patients living further from the specialist hospitals were more likely to be treated at a general hospital and less likely to receive potentially curative surgery.

		2000-2008 3,240		groups of 0-39km, 40-99km and 100+ km.	hospital (NASH) & closest general hospital.	
Tracey, et al. [57] AUSTRALIA 2014	Epithelial Ovarian Cancer	New South Wales Cancer Registry. 2000 - 2008. Sample = 3411	Survival	Straight-Line Distance. Distance was treated as a continuous variable and categorical variable for which it was grouped into equal quartiles - 0 - 5km 5.1-9.0km, 9.1-27.0, 27.1 - 187.0, 187.1+	Patients' Residence TO The closest gynaecological oncology Hospital	The study concluded that there was an increasing trend in the unadjusted hazard of death model with increase in distance to the closest public gynaecological Oncology hospital. The study reported that whilst they had used the closest hospital in their calculations only 37% of their sample had used their closest hospital.
Wang, et al. [58] USA 2008	Breast Cancer	Illinois Cancer Registry 1998 - 2000 Sample = 30,511 (9,077 were classed as late stage)	Late stage diagnosis	Straight-line Distance and Travel Time. Travel times were calculated using the ArcInfo network analysis module – using the minimum road distance when taking account of travel speed.	Patients' Residence (Population weight centroid of zip codes) TO The closest mammography facility & the closest GP.	The study found that travel time to mammography services had no statistically significant association with late stage risk. The study did find that as travel time to the nearest GP increased patients were more likely to have a later stage diagnosis.
Kidney studies						
Bello, et al. [59] CANADA 2012	Diabetes & Chronic Kidney Disease (jointly)	Alberta Kidney Disease Network & Provincial Health Ministry 2005 - 2009 Sample = 31,377	All-cause mortality, all cause hospitalisation, renal outcomes, ESRD initiation, progression to Egfr< 10mL/min/1.73m)	Road Distance. Distance was treated as a categorical variable. Using the following 6 categories 0-50, 50.1 - 100, 100.1 - 200 and >200km	Patients' Residence (6 digit postal code) TO The nearest nephrologist	The study found that when using a base of <50km, patients living >50km were less likely to visit a nephrologist, less likely to have follow up measurements of A1c and urinary albumin within a year. Plus have a higher change of all cause hospitalisation and all-cause mortality.
Bello, et al. [60] CANADA 2013	Patients with proteinuria (Kidney Damage)	Alberta Health and Wellness, Alberta Blue Cross, the Northern and Southern Alberta Renal Program and the provincial laboratories of Alberta. 2002 - 2009 Sample = 1,359,330	A range of health outcomes. ACEI/ARB use in ≥ 65 year olds, Statin use in ≥ 65 year olds, Timely Referral, All cause mortality, myocardial	Shortest Road distance. Distances were treated as a categorical variable using the groups : 0-50, 501 - 100, 100.1 - 200 and >200km.	Patients Residence (6 digit home postal code) TO The nearest nephrologist.	The study found a statistically significantly higher incidence of stroke and hospitalisations in those travelling a greater distance, but no association for the other outcome measures

			infarction, stroke, heart failure, doubling of SCr (Serum creatinine ratio), ESRD (end stage renal disease) and hospitalisations			
Cho, et al. [61] AUSTRALIA 2012	Peritonitis (Kidney)	ANZDATA Registry 2003 - 2008 Sample = 6,610	A range including - Peritonitis Free - Survival, first peritonitis episode, staphylococcus aureus peritonitis.	Road Distance. Calculated using Google Maps. Distance was treated as a categorical variable using the groupings - < 100km and ≥100km. The cut off was decided a priori as this is the minimum distance states provide patient assisted transport subsidy schemes to facilitate improved access.	Patients' Residence TO The nearest peritoneal dialysis unit.	The study found that living ≥100 km away from the nearest peritoneal dialysis unit was not significantly associated with time to first peritonitis episode. The study did find an association between living ≥ 100km away from the nearest unit and increased risk of Staphylococcus aureus peritonitis.
Judge, et al. [62] UK 2012	Renal Replacement Therapy (RRT) - Kidney	UK Renal Registry (UKRR) 2007 Incident population = 4607 Prevalent population = 36,775	Renal Replacement Therapy Incidence and Prevalence	Travel Time. Average speeds were assigned to roads and GIS transportation software Base Trans CAD used to estimate the minimum travel time. Travel time was treated as a continuous and categorical variable split into 4 groups: < 15mins, 15 - 29mins , 29 – 45, & 45+ mins	Patients' Residence (Centroid of the CAS Ward (average 2670 people in each ward)) TO The nearest Dialysis Unit	The study found that patients living >45 min travel time from the nearest dialysis unit were 20% less likely to commence or receive renal replacement therapy than those living < 15 min.
Miller, et al. [63] CANADA 2014	Chronic Kidney Disease	Canadian Organ Replacement Registry (CORR) 2000 - 2009	Incident Central Venous Catheter (CVC) use	Straight-line Distance. Distances were divided into 3 groups <5km, 5 - 20km and >20km	Patients' Residence (home postal code at dialysis initiation TO	The study found that increasing distance was associated with increased use of central venous catheters in incident dialysis patients.

		Sample = 26,449			The nearest dialysis centre	
Moist, et al. [64] USA 2008	Kidney Dialysis	Dialysis Outcomes and Practice Patterns Study (DOPPS) - questionnaire 1996 - 2001 (DOPPS 1) 2002 - 2004 (DOPPS 2) Sample = 20,994 (from 7 countries, France, Germany, Italy, Japan, Spain, UK and USA)	HRQOL (Health Related Quality of Life), Mortality, Adherence, withdrawal, hospitalisation and transplantation	Travel Time. The study was based on a survey which asked the question - How long does it take you to get to your dialysis unit or centre (1 way)? Respondents could answer ≤15mins, 16 - 30, 31 - 60 and >60mins. They were also asked how they usually travelled to the dialysis unit.	Patients' Residence TO The dialysis centre attended	The study found that longer travel times were associated with a greater adjusted relative risk of mortality. Health related quality of life scores were lower for those with longer travel times when compared with travelling < 15mins.
Thompson, et al. [65] USA 2012	Kidney Disease	United States Renal Data System. Jan 1995 – 2007 Sample = 726,347 (the study excluded patients with missing or invalid postcodes)	Mortality	Shortest Driving Distance. Distance was treated as a categorical variable. Using 5 categories: 0-10 miles, 11-15, 26-45, 46-100 and >100miles. The categories correspond to the 0 – 75th , 75-95th, 95th -99th, 99th-99.9th and >99.9th percentiles.	Patients' Residence (5 digit zip code at time of first renal replacement, dialysis or transplant) TO The closest Haemodialysis Centre	The study found that distance, but not living in a rural area was associated with increased mortality. The adjusted model identified a statistically significant hazard ratio between the reference case (0-10milles) and the 11-25 miles and >100miles categories, but not for other distance categories.
Thompson, et al. [66] USA 2013	Kidney	United States Renal Data System 2001 - 2010 Sample = 1,784	Quality of Care Indicators (90 days following haemodialysis therapy and at 1 year)	Shortest Road Distance. Distance was treated as a categorical variable. Using the following categories: ≤50km, 50.1 - 150km, 150.1 - 300, >300km.	Patients' Residence (5 digit zip code) TO The closest nephrologist.	The study found that patients were less likely to have seen a Nephrologist 90 days prior to starting haemodialysis therapy, and were more likely to have a sub optimal levels of phosphate control the further they lived from a haemodialysis centre.
Tonelli, et al. [67] CANADA 2007	Kidney Failure	Canadian Organ Replacement registry 1990 - 2000 Sample = 26,775	Mortality	Shortest Road Distance Calculated using postal data converted using www.melissadata.com and entered into ArcGIS. Distance was treated as a categorical variable using the	Patients' Residence (6 digit postal code) TO The practice location of the patients' nephrologist.	The study found that remote dwelling Canadians with kidney failure were significantly more likely to start renal replacement on Peritoneal Dialysis (PD) and switch to PD if their initial dialytic option was haemodialysis. The adjusted rates of death and the adjusted hazard ratios were significantly higher in those living ≥50km from the nephrologist compared to those < 50 km.

				groups of: <50km, 50.1 - 150km, 150.1 - 300 and >300km		
Tonelli, et al. [68] Canada 2007	Kidney (Haemodialysis)	Canadian Organ Replacement Register 1990 - 2000 (when the sample started dialysis) Sample = 18,722 (random sample of 75% of the patient population)	Mortality (from all causes) Then split by cause - infectious or cardiovascular	Shortest Road Distance Calculated using ArcGIS 9.1. Distance was treated as a categorical variable using the following groups - 0-50km, 50.1-150km, 150.1-300km, >300km	Patients' Residence TO The practice location of the attending nephrologist.	The study found that mortality associated with haemodialysis was greater for patients living further from their attending nephrologist. This was particularly evident for infectious causes.
Diabetes Studies						
Littenberg, et al. [69] USA 2006	Type 2 diabetes	Vermont Diabetes Information System. Adults completed postal surveys and were interviewed at home. Years Unknown Sample = 781 (131 insulin users & 650 non users)	Glycaemic Control Insulin Use	Shortest driving distance Calculated using ESRI ArcView 3.3 and a geographic data set of roads from Tele Atlas. Distance was treated as a continuous and categorical variable. Distances were grouped as <10km & > 10 km	Patients' Residence (home address) TO Primary care facility	The study found that insulin users had shorter driving distances to the healthcare facility than non-users. Longer driving distances were associated with poorer glycaemic control. The OR for those using insulin, living <10km, having glycaemic control was 2.29 (CI 1.35, 3,88; p = 0.002).
Strauss, et al. [70] USA 2006 (Data cross over with Littenberg et al 2006))	Diabetes	Vermont Diabetes Information system. Adults completed postal surveys and were interviewed at home (23% of the contacted population) July 2003 - March 2005 Sample = 973 (794 non insulin users & 179 insulin users)	Glycaemic Control (for insulin and non-insulin users)	Shortest Road Distance Calculated using a road network in ArcvIEW 3.3. Distance was modelled as a categorical variable. Patients were split into 3 equal groups <3.8km, 3.9 - 13.3km, ≥13.3km	Patients' Residence (home address) TO Primary care facility used.	The study identified that longer driving distances from the patients' home to the site of primary care were associated with poorer glycaemic control.
Zgibor, et al. [71] USA	Diabetes	Seven diabetes management centres in Southwestern	Controlled vs uncontrolled diabetes	Road Distance. Driving distance using the	Patients' Residence (home address)	The study found that living > 10 miles away significantly contributed to lower levels of glycaemic control for diabetes patients. Those who lived ≤ 10

2011		Pennsylvania. Jun 2005 - Jan 2007 Sample = 3,369		network analyst tool in ArcGIS. Distance was treated as a continuous and categorical variable. Distance was divided into 2 categories ≤10 miles and >10 miles. The average distance was 13.3 miles.	TO The diabetes treatment centre attended.	miles from the diabetes treatment facility were 2.5 times more likely to have improved their levels of glycaemic control between their first and last visits.
Transplant Studies						
Goldberg, et al. [72] USA 2014	Liver Transplant	Veterans Health administrations integrated, national electronic medical records linked to organ procurement and transplantation network 2003 - 2010 Sample = 50,637	Being waitlisted for a liver transplant, having a liver transplant and mortality	Straight-line Distance. Distance was treated as both a continuous and categorical variable. 5 distance categories: 0 - 100miles, 101-200, 201-300, 301-500, >500miles	Veterans Admission (VA) Centre TO The Veterans Admission Transplant Centre (VATC)	The greater the distance from a VATC or any transplant centre was associated with a lower likelihood of being put on a waiting list or receiving a transplant and greater likelihood of death.
Redhage, et al. [73] USA 2013	Liver Transplant	Hospital Data and HRQOL (Health Related Quality of Life) survey. Dates unknown Sample = 706	Longitudinal HRQOL was measured using the SF-36 Health Survey and a rolling enrolment process.	Distance [unspecified] Distance treated as a continuous variable. The distance range was 0 – 2261 miles and average 179.	Patients' Residence (home address) TO The transplant centre	The study found that increased distance to the transplant centre was associated with a decreased post-transplant physical HRQOL, but that there was no association between distance and pre- transplant HRQOL.
Thabut, et al. [74] USA 2012	Lung Transplant	Transplant Registry 2001- 2009 Sample = 14,015	Listing for a transplant, receipt of a transplant and survival.	Straight-line Distance. Using ArcGIS Software. Distance was treated as a categorical variable using two different sets of groupings. Firstly - the following groups - 0 - 50 miles, 51 - 100 miles, 101 - 150 miles, 151 - 200 miles and > 200 miles. Secondly - 6	Patients' Residence (centroid of the residential zip code) TO The nearest adult lung transplant centre	The study found that the distance from a lung transplant centre was inversely associated with the hazard of being listed (both before and after the introduction of the lung allocation score). Once waitlisted distance from the closest centre was not associated with differences in survival.

				categories 0 - 50th percentile, 50th - 75th percentile, 75th - 90th percentile, 90th to 95th percentile, 95th - 99th percentile and + 99th.		
Zorzi, et al. [75] USA 2012	Liver Transplant	United Network for Organ Sharing Jan 2004 – July 2010 Sample = 5,673	Mortality & being dropped from a waiting list due to being too sick.	Straight-line Distance. Distance were calculated using ww.zip-codes.com Distance was considered as a continuous & categorical variable and divided into the following 3 groups: <30miles, 30 -60 miles and >60 miles	Patients' Residence TO The nearest liver specialised transplant centre & nearest 300 bed hospital.	The study found that increased distance from a specialised liver transplant centre was associated with an increased likelihood of death. The likelihood of wait list drop out was significantly higher for patients living > 30 miles from the specialised liver transplant centre.
Obesity Studies						
Jennings, et al. [76] UK 2013	Obesity (Laparoscopic adjustable gastric banding - LAGB)	Hospital Database. < 2010. Sample = 227	Compliance with follow up appointments.	Road Distance. Calculated using Google Maps. Distance was treated as a continuous variable. The average distance for perfect attenders is 15.3 miles and non-attendees are 21.1.miles.	Patients' Residence (Home Address) TO The treating hospital	The study identified that compliance with follow up following LAGB is associated with better weight loss. Patients living closer to the treating hospital were more likely to regularly attend follow up. The study reported longer public transport journey times in the non-attending group - but did not include this in the analysis.
Lara, et al. [77] USA 2005	Obesity	Gundersen Lutheran Medical Centre data. Sept 2001 - April 2003 Sample = 150	Compliance with follow up at 3, 6 ,9 and 12 month appointments	Straight-line Distance. Distances were treated as a categorical variable using groups: <50 miles 50 - 100 miles and >100 miles	Patients' Residence (zip code TO The Clinic they were treated/ followed up at.	The study found that travel distance from the clinic did not significantly affect compliance at the initial follow-up, 3-month, and 12-month appointments. However, distance did affect compliance at the 6-month appointment and significantly affected compliance at the 9-month appointment.
Sivagnanam and Rhodes [78] UK 2010	Obesity - Laparoscopic adjustable gastric band (LAGB)	The Norwich Spire Hospital. October 1997 - March 2009. Sample = 150	Follow up and weight loss	Distance. Method not reported. Distance was treated as a categorical variable and split into the following distance groups <10, 10 - 20, 20 - 30 and > 30. (all miles)	Patients' Residence TO The Norwich Spire Hospital.	The study found that patients attended fewer follow up clinics, as distance increased from the patient's home address. The percentage estimated weight loss was lowest in the group that lived furthest from the hospital, but this was not statistically significant.

				87% of the patients lived < 50 miles from the hospital.		
Mental Health Studies						
McCarthy, et al. [79] USA 2007	Mental Health - Schizophrenia or bipolar disorder	National Veterans Affairs (VA) administrative data. Patients who received a diagnosis of schizophrenia or bipolar disorder in the year Oct 1997 - Sept 2008 and survived the year. Sample = 163,656	Continuity - measured by time to first 12 month gap in VA health services utilisation	Straight-line Distance. Distance was treated as a continuous variable. Average distance to the nearest provider was 11.8 miles.	Patients' Residence (population centroid of the patients zip code) TO The nearest VA providers of substantial psychiatric services or community based outpatient clinics serving at least 500 unique patients where at least 20% were mental health visits.	The study found that patients who had a 12 month gap in VA services utilisation were more likely to have a lower Charlson comorbidity score and live further away. Living ≥25 miles from VA care was associated with a greater likelihood of a gap in VA health utilisation. The hazard ratio associated with each 5 miles further from psychiatric services was 1.011.
Joseph and Boeckh [80] CANADA 1981	Mental Health	Provincial health records 1976 Sample = 1767 inpatients & 883 outpatients	Seriousness of diagnosis	Distance. Distance from Peterborough Ontario. They do not provide any other information on method of calculation.	Patients' Residence TO Peterborough Ontario	The study concluded that severity of diagnosis increased as distance travelled increased.
Skarsvag and Wynn [81] NORWAY 2004	Mental Health Psychiatric	Regional population & actual patient data from the Stokmarknes Clinic in Nordland 1992 - 1996 Sample = 10,996 (total population) Sample = 1,834 treated population.	Use of an outpatient clinic	Travel Time. Calculated from information gathered from local bus and ferry companies. The study treated travel time as a categorical variable using the cut off of 35 minutes.	All residential addresses in the local area & actual patient attendees. TO The outpatient clinic at Stokmarknes.	The study found that a significantly higher proportion of those living < 35 mins from the clinic had used the clinics services than > 35mins.
Other studies						
Allen et al. [82] USA	Sleep Apnea	University of British Columbia Hospital Sleep Disorders Clinic Included referred	Severity of obstructive sleep apnea	Travel Time. Calculated using DMTI routing data and the ArcGIS Network analyst function.	Patients' Residence (postcode) TO The sleep disorder clinic	The study found that travel time to the sleep clinic was a predictor of obstructive sleep apnea severity (controlling for sex, age, obesity and education). Every 10 min increase in travel time was associated with an increase of 1.4 events per hour in the apnea-hypopnea index.

2016		patients whose travel times were < 1 hour. May 2003 – July 2011. 1,275		Travel time was treated as a continuous variable and categorical variable. The mean travel time was 20.8 mins. The cut point for the categorical variable was the mean time.		
Arcury, et al.[83] USA 2005	Non specific - Health care visits	Survey of adults in 12 rural Appalachian North Carolina Counties. Personal interviews in participants homes. 1999 - 2000. Sample = 1,059	Number of regular check-up care visits, chronic care visits and acute care visits	Straight-line Distance. Distance to the healthcare facility was based on respondents stating which hospital, clinic or doctor they would normally go to for "a really bad emergency", A less serious emergency, and for regular care. The average distance for regular check-up visits was 14 miles, for chronic care visits 18 miles and serious emergencies 18.58miles.	Patients' Residence (Survey at respondents homes) TO The self-reported hospital, GP, clinic that they would normally go to for a really bad emergency, a less serious emergency or for regular care.	The study found that distance was significantly associated with the number of regular check-up care visits and chronic care visits. Distance was not associated with acute care visits. They identified that those people with a driving license had an estimated 1.58 times more regular care visits and 2.3 times more chronic care visits.
Ballard, et al.[84] USA 1994	Non-specific.	Medicare hospitalization data (MEDPAR) 1998 Sample = 13,596 Two groups – patients referred to Mayo Rochester hospitals and separately national referral hospitals.	30 day mortality	Distance No information in paper on specific method. Distance was split into the categories of <10 miles and ≥ 10 miles.	Patients' Residence (zip code) TO The hospital attended (zip code)	The study found that increased distance from the patient's residence to the hospital that they were treated in was independently associated with higher 30 day mortality rates.
Chou, et al.[85] USA 2012	Coronary artery bypass graft (CABG)	Pennsylvania HealthCare Cost Containment Council 1995 - 2005 Sample = 102,858	In hospital mortality and readmission	Straight-line distance. Distance was treated as a continuous variable. Average distance 14.9 miles.	Patients' Residence (Centroid of the patient's residential zip code) TO The admitting hospital	The study found that high risk Coronary Artery bypass graft patients living further from the admitting hospital had increased in-hospital mortality.
Etzioni, et al.[86] USA	Any Surgical Operation	National Surgical Quality Improvement Project (NSQIP)	30 day surgical outcomes	Distance No information on method.	Patients' Residence (zip code centroid)	The study found that patients who lived closer were less likely to have a serious complication at 30 days and had better outcomes than predicted.

2013		database - for a large tertiary care institution. 2006 - 2009 Sample = 6,938 procedures		Distances were treated as a categorical variable and split into quintiles by procedure category. This allowed the study to take into account that patients travelled further for more complicated operations. The average distance was 226 miles.	TO The tertiary hospital attended.	
Evans et al. [87] USA 2016	HIV with Severe sepsis	University of Virginia Clinical data repository 2001 – [not stated] 74	In hospital Mortality	Distance Method unspecified. Dichotomised into ≤40miles and >40 miles	Patients' Residence (assumed) TO The University of Virginia Ryan White HIV clinic	The study found that after adjusting for severity of illness and respiratory failure, patients living >40 miles from the clinic had a fourfold increased risk of in-hospital mortality compared to ≤40 miles.
Haynes, et al. [88] UK 1999	Inpatient Episodes	Regional Health Authority. 1991 - 1993 Sample = 470,650 acute episodes, 13,425 psychiatric episodes and 36,909 geriatric episodes.	Healthcare episodes	Straight-line Distance. Distance was treated as a continuous variable. The furthest distance to the GP was 8km and to the acute hospitals 41km.	Patients' Residence (population weighted centroid of the patients ward) TO The nearest district general hospital. & Patients' Residence TO The nearest GP surgery.	The study found that after controlling for key confounders distance to hospital was a significant predictor of hospital episodes, especially psychiatric episodes. The study found that distance to the GP was only significantly associated with reductions in acute episodes in hospital.
Jackson, et al. [7] USA 2013	Colorectal Surgery	The National Surgical Quality Improvement Programme Database. May 2003 - April 2011 Sample = 866	Length of Stay	Road Distance with the shortest travel time. Distance was treated as a continuous variable. The mean distance travelled was 146.9 miles (range 2 - 2984). The study transformed distance and length of stay onto the log scale due to non-normal distributions.	Patients' Residence (5 digit zip code) TO The hospital treated at (5 digit zip code).	The study found that in the adjusted model increased travel distance from a patient's residence to the hospital was associated with an increase in length of stay.
Jackson, et al. [89] USA	Elective Pancreatic Surgery	Local National Surgery Quality Improvement database.	Length of Stay	Road Distance (shortest travel time)	Patients' Residence (5 digit zip code)	The study found (in the general model) that for each additional 100 miles travelled, the length of hospital stay increased by 2%.

2014		2005 - 2011 Sample = 243		Distance was treated as a continuous variable. The distances ranged from 3 - 3006 miles.	TO The hospital treated at (5 digit zip code)	
Jones, et al. [90] UK 1999	Asthma	Regional Deaths System for East Anglia. 1985 - 1995 Sample = 768 (of which asthma was the underlying cause of death in 365 of these).	Mortality	Travel Times. Travel times were treated as categorical & continuous variables. The groupings used for travel to the GP were 0 - 4mins >4 - 6 mins, >6 - 9 mins and ≥ 9mins. The minimum travel time was 3 minutes and the maximum 20.8 minutes. The groupings used for travel time to the hospital were 0 - 10, > 10 - 20, > 20-30, ≥ 30mins. The minimum time to the hospital was 4.4 minutes and the maximum 54.7 minutes.	Patients Residence (starting point measured at the ward level-average number of households = 2,726) TO The nearest GP and the nearest acute hospital with over 200 beds.	The study identified an association between asthma mortality and increasing travel time to the nearest acute hospital. The study found no relationship between distance to the GP and asthma mortality rates.
Lake, et al. [91] UK 2011	TB - treatment with full course of anti TB therapy	National enhanced TB surveillance system (ETS) 2001 - 2006 Sample = 21,954	Completion of TB Treatment	Road Distance. Distance was treated as a categorical variable using the groups of < 7.3km and > 7.3km.	Patients' Residence (postcode) TO The TB treatment facility	The results indicate that attending a TB centre with low case load or greater distance was associated with poorer treatment outcomes. The study identified that distance to a TB treatment centre was insignificant for patients native to the country (UK).
Lankila et al. [92] Finland 2016	Primary Healthcare Attendance	Northern Finland 1966 Birth Cohort Questionnaire administered 1997 (cohort were all 31 years old) 4,503	Use of local health centres	Shortest Road Distance Calculated using the Finish road network data (Digiroad) using ESRI ArcGIS 10. Distance was treated as a categorical variable using 0-1.9km, 2 – 4.9 km 5.0-9.9 km and ≥10.0km	Patients' Residence TO The municipalities health centre facility (or where there were more than one – the closest was used)	The study found that the number of people attending health centres and mean number of visits declined with distance for people living in rural areas, but this was not significant, but the opposite was the case for the sub group in urban areas travelling ≥10.0km compared to 0-1.9km.
Monnet [93]	Hepatitis C	Registry Data 1994 - 2001	Hepatitis C detection rates	Road Distance. Calculated using Chrono Map in	Patients' Residence (geometric centroid of the patients municipality of	The study found that the detection rate for Hepatitis C decreased in each of the studies socioeconomic clusters as distance to the GP increased.

FRANCE 2008		sample = 1,938		MapInfo with the 1997 Michelin light road network table (which includes major roads). Distance was treated as a continuous variable.	residence) TO The GP (geometric centroid of municipality)	
Prue, et al. [94] USA 1979	Alcohol Abuse	Jackson Veterans Administration Hospital. Years Unknown, Sample = 40.	Aftercare attendance.	Road Distance. Calculated as total miles. Split into "miles to " the nearest highway and "miles on" the nearest highway. Distance was treated as a continuous variable. The range of distances was (12 - 378 miles).	Patients' Residence (home address) TO The aftercare facility	The study found that the number of "miles to" and "miles on" the highway significantly affected the probability of attendance at an alcohol abuse aftercare appointment. Distance to the major highway was more predictive of attendance than the miles on the major highway.
Singh, et al. [95] CANADA 2014	Cardiac	Brunswick Cardiac Centre. 2004 - 2011. Sample = 3,897	30 day rates of adverse events following non-emergency cardiac surgery	Road Distance. Distance was treated as a categorical variable using the following groupings: 0-50km, 50 - 100km, 100 - 150km, 150 - 200km, 200 - 250km and >250km.	Patients' Residence (Home address) TO The Cardiac Surgery Centre	The study found that increased distance from the cardiac surgery centre was independently associated with a greater likelihood of experiencing an adverse event at 30 days.

Table 3: Included studies identifying evidence of a distance bias association

Author Country	Disease / Procedure	Source, Years & Sample size	Health Outcome	Distance/ travel time measurement	Origin and Destination	Summary of key results
Cancer Studies						
Bristow et al.[96] USA 2015	Ovarian Cancer (Advanced Stage)	Californian Cancer Registry 1996 – 2006 11,765	Mortality	Straight-line Distance Calculated using ESRI ArcMap 10.0. Distance was treated as a categorical variable using quintiles. Categories for hospital attended: <5km, 5-9, 10-16, 17-31, ≥32km. Categories for nearest high volume hospital: <9km, 9-17, 11-20, 21-49 & ≥80km. 80% of patients travelled ≤28.3km to the hospital they were treated at. 80% of patients were ≤ 79.6km to the nearest high volume hospital.	Patients' Residence TO The hospital treated at and the nearest high volume hospital.	The study found that travelling 5-9km, 17-31 km and ≥32km to the hospital compared those travelling <5km (reference case) was associated with a reduction in the risk of mortality. After controlling for hospital size and adherence to treatment guidelines 5-9km and 17-31km compared to the reference case were still significant. The opposite case was found for distance to the nearest high volume hospital for patients travelling ≥80km compared to the reference case of <9km. This was no longer significant after controlling for adherence to treatment guidelines.
Lamont, et al.[97] UK 2003	Cancer	4 phase II chemo radiotherapy studies conducted at the University of Chicago. 1993 - 2000 Sample = 110.	Survival	Distance. Driving miles (using an "internet based mapping engine"). Distances were treated as a categorical variable and split into two groups ≤ 15 miles (45 patients) and > 15 miles (67 patients)	Patients Residence (exact address) TO The University of Chicago hospital	The study found a positive association between the distance that patients travelled and survival. Those living > 15 miles had only 1/3 of the hazard of death than those living ≤15 miles. With every 10 miles that a patient travelled the hazard of death declined by 3.2%.
Lenhard Jr, et al.[98] USA 1987	Multiple Myeloma	Centralised Cancer Patient Data System. 1977 - 1982. Sample = 1,479	Survival	Distance. Distance was treated as a categorical variable using the following groups - 0 - 9 miles, 10 - 49 miles, 50 - 149 miles, and ≥ 150miles	Patients' Residence (zip code) TO The treating centre (zip code area)	The study found that survival improved with increasing distance travelled to treatment centres.

Lipe, et al. [99] USA 2012	Bone Marrow Transplant for Multiple Melanoma	Dartmouth Hitchcock Medical Centre transplant registry 1996 - 2009 Sample = 77	Survival (OS and progression free survival)	Straight-line Distance. Calculated using www.melissadata.com. Distance was treated as a continuous variable and categorical variable split into the groups of < 50miles and > 50 miles	Patients' Residence TO The Dartmouth Hitchcock Medical Centre	The study found that increasing distance from the transplant centre was associated with improved overall survival. The authors identified that this could be due to a referral bias, but could also be due to a healthier and more motivated groups of patients living further away.
Wasif, et al. [100] USA 2104	Gastrointestinal Cancer	National Cancer Database. 2003 – 2009 Sample = 77	Survival	Distance. [Method not specified] Distance was treated as a continuous variable and categorical variable split into the groups of <50 miles and >50 miles	Patient' Residence (zip code centroid) TO The treatment facility zip code centroid	The study found that adjusted hazard ratios were significantly lower for patients travelling > 50 miles compared to < 50 miles. This was true for liver, oesophageal and pancreatic cancer. They concluded that those that travelled > 50 miles to the treatment facility had lower 30 day mortality rates.
Other Studies						
DeNino, et al. [8] USA 2010	Obesity (Gastric Band)	Teaching hospital patients Nov 2008 - Nov 2009 Sample = 116	Follow Up Compliance and Weight Loss	Road Distance. Calculated using Google Maps. Distance was treated as a continuous variable. The average distance to the hospital was 39.5 miles.	Patients' Residence (exact address) TO The hospital treated at.	The study found a weak relationship between increased travel distance to the hospital and increased weight loss. Travel distance was found not to be significant for attending follow up visits.

Table 4: Included studies identifying no association

Author Country	Disease / Procedure	Source, Years & Sample size	Health Outcome	Distance/ travel time measurement	Origin and Destination	Summary of key results
Cancer Studies						
Celaya, et al. [101] USA 2010	Breast Cancer	New Hampshire State Cancer Registry (NHSCR) 1998 - 2004 Sample = 5,966	Stage at diagnosis	Driving Time and Road Distance. Calculated using ESRI ArcGIS and data from ESRI on street networks, posted speed limits and driving distance. Distance and travel time were treated as categorical variables. Using the following groupings: < 5 miles, 5 - <10 miles, 10 - < 15.0 miles, ≥15 miles. For travel time < 5 mins, 5 - < 10 mins and ≥ 10 mins	Patients' Residence (Addresses of patients were geocoded to an exact street address(91%) or to the zip code centroid if only a post office box or rural route address was available.) TO The nearest mammography facility.	The study identified no significant association between later stage breast cancer and travel time to the nearest mammography facility. They did identify that there was good access (patients did not have to travel a large distance) to mammography facilities in the area studied, as shown by the categorical groupings.
Cosford, et al. [102] UK 1997	Cancer	Cancer Registry 1991 Sample = described as the no. of people in each local authority district attending hospital with a diagnosis of cancer and the no. who received radiotherapy in that year.	Radiotherapy uptake	Travel Time. Modelled used to obtain off peak drive times + use of "commercially available computer programme". Travel time was treated as a continuous variable. Maximum travel times 1 hour.	Population weighted centroid of 14 different local authorities TO The nearest cancer centre serving the area.	The study found no significant relationship between overall radiotherapy uptake and travel times.
Crawford, et al. [103] UK 2012	Colorectal Cancer	Northern and Yorkshire Cancer Registry and Information Service. 1994 – 2002 Sample = 39,619	Stage of diagnosis & receipt of treatment	Travel Time. Shortest road route and average driving speeds along the routes by road class. Travel times were split into quartiles.	Patients' Residence TO The nearest hospital providing diagnostic and surgical treatment services for bowel cancer.	The study found no effect of travel time distance on stage of diagnosis or receipt of treatment. They also found no interaction effects between deprivation and travel time.

Gunderson, et al. [104] USA 2013	Cervical Cancer	Medical Records 2006 - 2011 Sample = 219	Overall Survival Progression free survival	Straight- line Distance. Distance was treated as a categorical variable. Using the following groups: <30 miles and >30 miles	Patients' Residence (zip code) TO The treating hospital (if the patient underwent surgery) otherwise the radiation centre.	The study found no significant difference between patients travelling <30 miles and those travelling >30 miles for survival. They found that non Caucasians were less likely to travel > 30 miles.
Heelan and McKenna [105] IRELAND 2011	Cancer	Melanoma Database. 2000 - 2009 Sample = 106	Breslow Thickness	Driving Distance. The automobile Association route planner was used to estimate distance travelled by road. Data was treated as a categorical variable using the groupings of < 30km and >30km. The median distance was 33.3km (range 0.2 - 123.12km)	Patients' Residence TO The hospital attended.	The study found no significant association between distance travelled and Breslow thickness on presentation. The study concluded that this could have been due to the type of patients in the sample (high number of thick lesions) in both distance categories.
Henry, et al. [106] USA 2013	Breast Cancer	US North American Association of Central Cancer Registries. Patients diagnosed 2004 - 2006 Sample = 174,609	Stage at diagnosis	Travel Times. The study calculated 3 accessibility measures including shortest road network drive time. This used the NAACCR shortest path calculator. - https://www.naaccr.org/Research/ShortestPathFinder.aspx Travel times were treated as categorical variable using the following groups - ≤ 5 mins, > 5 - 10, > 10 - 20, > 20 - 30, > 30. 93% of the breast cancer cases lived < 20 mins from the nearest mammography facility and only 2.8 % lived > 30mins.	Road nearest the population weighted centroid of each census tract TO The nearest FDA certified mammography facility	The study found that after adjusting for poverty there was no impact of distance on late stage diagnosis. They found that poverty was independently associated with late stage diagnosis.
Henry, et al. [107] USA 2011	Breast cancer	10 state population based cancer registries - covering 30% of the population of the USA. Patients diagnosed 2004 - 2006 Sample = 161,619	Stage at Diagnosis	Travel Time. Travel time was modelled as both a continuous and categorical variable. There were 7 categories ranging from < 10 mins to ≥ 60 mins. 76% of the women lived <20 mins from their diagnosing facility & 93% < 20mins from the nearest mammography facility.	Patients' Residence (residential street address (87%) or postal delivery area centroid (8%). TO The diagnosing facility and nearest facility.	The study concluded that increased travel time was not a determinant of late stage diagnosis. They found that insurance status, race and poverty were associated with risks for a late stage diagnosis of breast cancer.
Khera et al. [108]	Hematopoietic cell	Fred Hutchinson Cancer Research Centre/	Non relapse mortality	Distance	Patients' Residence (zip code)	The study found no relationship between increasing distance and non-relapse mortality,

USA 2016	transplantation	Seattle Cancer Care Alliance 2000 – 2010 2,849	Relapse mortality Survival at 200 days	Method unspecified. Distance was treated as a continuous and categorical variable. Categories ≤100km, 100- 500, 500, 1000 and > 1000km from the centre were used. Categories of <170km and ≥170 km were used to assess mortality. Median distance 263km (range 0 – 2740km)	TO The transplant centre (Fred Hutchinson Cancer Research Centre)	relapse mortality and survival at 200 days. The study does state that patients are required to stay within 30 minutes of the hospital for the first 80 to 100 days, which allows them to be closer (for most patients than their residential address) for any early issues. After this patients were followed up via telemedicine in addition to travelling to the clinics.
Meersman, et al. [109] USA 2009	Breast Cancer	California Health Interview survey 2001 Sample = 4,249	Mammography uptake	Straight-line Distance. Distances were treated as categorical variable and split into the following quartiles: 0 - 0.53 miles, 0.54 - 1.07 miles,1.09 - 1.82 miles and 1.83 - 26.5 miles. The study also calculated the number of public transit stops within 3 miles of the respondent and split these into quartiles.	Patients' Residence (70% of the sample were geocoded based on the nearest street to their residence, 30% to their zip code centroid). TO The nearest mammography facility.	The study did not use the distance calculations in the final model (as they were not significant)- but instead used mammography density within 2 miles of a patient's residence instead - which was found to be significant. The number of bus stops within 3 miles was not significant. This indicated that density of mammography facilities and not distance was the critical factor.
Ragon, et al. [110] USA 2014	Allogeneic hematopoietic stem cell transplantation (HSCT)	Transplant data team and medical records 2006 - 2012 Sample = 299	Survival	Straight-line Distance. Distance from the transplant centre was split into 2 groups of <170km and >170km. This represented a cut off at 75th percentile.	Patients Residence (Zip code at the time of the transplant) TO The medical centre where they were treated.	The study found that distance did not impact on the overall survival rate.
Sauerzapf, et al. [111] UK 2008	Breast Cancer	Northern and Yorkshire Cancer Registry Information Service. 1994 - 2002 Sample = 6,014	Breast conserving surgery vs mastectomy & whether the patient had received radiotherapy following breast conserving surgery.	Travel Time. Fastest Travel time using the road network. Using ArcGIS and the Meridian digital road network. Sections of the road were assigned average car travel times. Distances were treated as categorical variables using the categories of ≤30 mins, 30 - 60 mins > 60 mins. The study also collected information on those living within 800m of a frequent bus service.	Patients' Residence (postcode) TO The closest hospital where radiotherapy was available.	The study found that the choice of breast conserving surgery or receiving radiotherapy was not associated with the estimated travel time. They did find that travel time to radiotherapy was only significant as a predictor of surgery choice for patients living >800 m from a frequent bus service.

Schroen and Lohr [112] USA 2009	Breast Cancer	Virginia Cancer Registry 2000 - 2001 Sample = 8,170	Invasive tumour size at diagnosis	Shortest Road Distance. Calculated using ArcGIS. Distance was treated as a continuous variable. The average distance was 5.7 miles and only 5% of the patients lived >20 miles away.	Patients' Residence TO The nearest mammography facility.	The study found that distance to the nearest mammography facility had no consistent relationship between invasive tumour size at diagnosis in the adjusted model. They found that only advanced age was a predictor of invasive tumour size at diagnosis
Other Studies						
Firozvi, et al. [113] USA 2008	Liver Transplant	Medical Centre Transplant Database. 2002 - 2005 (censor date 2005) Sample = 166.	Listing status, time required to list, survival once listed, transplantation and 1yr post transplantation survival.	Travel Time. Calculated using Yahoo! Maps. Travel time was treated as a categorical variable using > 3 hour and ≤3 hour. 38 people had travel times > 3. The range of travel times was 0 - 7 hours.	Patients' Residence (where not available the patients home town or city centre) TO The specific transplant centre	The study found that those patients living > 3 hours away from a transplant centre had comparable outcomes to those living closer.
Leese, et al. [114] UK 2013	Diabetes Related Foot Disease	Three linked data sets. Scottish Care Information Diabetes Collaboration - Tayside Regional Diabetes Register, Foot ulcer dataset, Amputation dataset. 2004 - 2006 Sample = 15,983. 670 (with new foot ulcers) 99 (with an amputation)	Occurrence of a new foot ulcer or amputation	Travel Time (using road distance) Travel time was treated as a continuous variable. The average time to the GP was 6.48 minutes, average time to the local hospital was 28.47 minutes.	Patients' Residence TO The local hospital clinic and local GP	The study concluded that distance from the GP or hospital clinic and lack of attendance at community retinal screening did not predict a foot ulceration or amputation. They did find that being socially deprived was significantly associated with foot ulceration.
Markin, et al. [115] USA 2011	Pulmonary Arterial Hypertension	PAH Disease Management (REVEAL). Years Unknown. Sample = 638	Delayed diagnosis	Distance. (method not reported) Distance was treated as a categorical variable using the grouping of < 50miles vs >50 miles.	Patients' Residence TO The pulmonary hypertension (PH) centre	The study concluded that distance from the PH centre was not shown to be associated with a delayed diagnosis, lower likelihood of early treatment with an IV/SC prostacyclin analog, or a worse functional class at diagnosis.
Rodkey, et al. [116] USA	Heart Transplant	Transplantation hospital charts, local hospital records and direct patient and family	Rejection episodes, No. of endomyocar	Distance. Distance was calculated using the Rand McNally TripMaker Version 1.1.	Primary city of residence TO The transplant centre	The study concluded that long distance management of heart transplant recipients is successful and is not associated with an increase in adverse outcomes. Patients living further away

1997		contact. 1984 - 1995 Sample = 312	dial biopsies, ED visits, hospital admissions, infections, coronary allograft vasculopathy, malignancies re-transplantation and death	Distance was treated as a categorical variable using the groups 0 - 150miles 151 - 300 miles and >300miles. 207 patients lived in group 1, 69 patients lived in group 2 and 36 in group 3. (range 2 - 1218 miles)		had similar results to those in the closest category (0 – 151 miles).
Stoller, et al. [117] USA 2005	1-Antitrypsin (AAT) deficiency	The results are based on a 4 page mailed out survey to AAT deficient individuals. Achieving a 38% response rate. 2003 Sample = 1,851 (Achieving a 38% response rate)	Diagnostic delay	Distance. Calculated using GIS software Distance was treated as a categorical variable using the groups of < 50 miles and ≥ 50 miles to the CRC. 38% of the survey respondents lived within 50 miles of a CRC.	Patients' Residence (zip code) TO The nearest designated clinical resource centre.	The study found that neither urban residence nor living near a centre with expertise (living within 50 miles) was associated with a shortened delay in diagnosis.
Swan-Kremeier, et al. [118] USA 2005	Eating Disorder	Contact records, clinical records and appointment records of patients at a treatment centre. Unknown date. Sample = 139 (37 completers & 102 drop outers)	Attendance Patterns and Treatment Attrition	Straight-line Distance. Distance was treated as a continuous variable. The average distance for completers was 43.9 miles and the average distance for drop outers was 29.8 miles.	Patients' Residence To The treatment centre	The study concluded that distance travelled to the treatment site was not significantly different between the two groups (drop outers and completers).
Tonelli, et al. [119] CANADA 2006	Kidney transplantation	Canadian Organ Replacement Registry. Patients starting dialysis 1996 - 2000 (followed until Dec 2001)	Likelihood of Transplant	Distance (No information on distance calculations). Distance was treated as a categorical variable using the groups - < 50km, 50.1 - 150km, 150.1 - 300km and > 300km.	Patients' Residence (at the time of starting dialysis) TO The nearest transplant centre	The study found that the likelihood of a transplant was not affected by the distance to the nearest transplant centre.

		Sample = 7,034				

The studies were diverse in nature; however five of the distance bias studies (table 3) reported a positive relationship between increasing travel distance and better survival rates for cancer patients ([99]-[96 97]). Lipe et al. [99] concluded that survival rates were higher for those travelling further to the transplant centre potentially due to referral bias, but also patients living further away being healthier and more motivated. Other effects identified by the review include the study by Kim et al.[42] who highlighted a U shaped all-cause mortality relationship. When the data was split into three categories of distance travelled, those in the middle (20 – 30 km) category had lower all-cause mortality than those living in the closer or further away categories. This indicated that there was something different about this geographical area and the people living in it. This effect was evidence in other papers, but not at statistically significant levels.

Over 50% of the studies reported on cancer (55% in table 2, 83% in table 3 and 53% in table 4) with the majority being breast or colorectal studies. Other diseases and outcomes are summarised in tables 2 - 4. The studies covered a wide range of contexts and travel requirements for patients. Studies that identified a distance decay association ranged from a very localised cohort of patients - average distances to the healthcare facility of 13.3 miles for treatment for diabetes [71], to > 6 hours travel in Canada for breast and colorectal cancer survival [25], to > 300km for remote kidney dialysis [67], and an inter country study with a range of 1km – 870km for treatment for malignant brain tumour [41]. These differences reflect both the geographical sizes of the countries in question and the need to travel for specialist treatment. There was no obvious difference in the distances and travel times between the three groups (distance decay, distance bias and no association).

A wide variety of methods and data (e.g. registry data, patient surveys, hospital data) were used to explore the relationship. There were differences in the patient origins and healthcare destinations used to determine the patient journeys. The majority used the patients address (full address/postcode/ zip code) as the origin for the journey, but others used the centroids of larger geographical areas [62], [34], [90],[19] or the referring hospital [72] or the city of residence [116]. It was recognised that for the longitudinal studies there was a potential for patients to move addresses, but no studies used differing residential locations where people moved house to calculate the distances and travel times. For example, Dejardin et al. [27] applied the residential location at the time of diagnosis and assumed this remained constant during treatment. Forty eight percent of the studies had access to data on the nearest healthcare facility to the patient, with the remainder using the actual healthcare facility attended. Bristow et al. [20] and Henry et al. [107] calculated both the nearest and actual facility attended. All studies who found a distance bias association used the actual healthcare facility attended by the patients in their study.

The methods used for calculating travel distance/ travel time in the studies ranged from straight-line distance (Euclidean Distance), travel distance using a road network (either shortest distance or shortest travel time); travel speed using the shortest distance by road network (with and without adjusted road network speeds) or patients' self-reported travel times. As shown in table 1, 19% of the studies did not clearly state how they had calculated this variable. One hundred percent of the studies in the distance bias association group calculated travel distance, 77% in the distance decay association group and 63% in the group that identified no association.

DISCUSSION

The results were mixed. Eighty three studies identified evidence of distance decay association, nineteen no evidence and six studies evidence of distance bias association. Thus the majority of studies reported a negative correlation between distance/ travel time to healthcare facilities and health outcomes. This was true across a multitude of disease groups, geographical distances and boundaries. The wide range of methods, sources of data, disease areas and outcome measures and ranges of distances travelled add to the complexity of the comparisons. The focus of this discussion is on the key differences in the way that the distances and travel times were calculated and analysed and what observations from the studies have heightened potential reasons to suggest an association between distance/ travel time and health outcomes.

Travelling to healthcare

The critical elements of calculating an accurate representation of the distances and travel times that the patients have endured requires a starting location for the journey (e.g. patient home address) [1], end point (healthcare facility) and method for accounting for the estimated route taken between these two points. The included studies differed on all three of these inputs. Where the patient's address was unavailable less specific geographical identifiers were used by the studies, ranging from patients postcode [91] , zip code centroid [29], centroid of a census district [62] referal hospital [72], to the centroid of town of residence [116] to a mixture of the above methods where data was missing at the less aggregated geographical levels [101]. Using an origin point that is less accurate than the patient's home address has the potential to reduce the accuracy of the results, as it may influence the route taken affecting the distances and travel times.

The geographical data available for the healthcare facilities attended also differed across studies. Fifty two percent of the studies had the address of the healthcare facility attended by the patient. The remainder used the address of the nearest facility to the patient, as a proxy. Knowing how realistic the proxy measure is would be a benefit, as it may dramatically change the distances/ travel times calculated. For example Tracey el al. [57] identified in their study that only 37% of the patients attended the nearest facility, so using this as the proxy would underestimate the distances travelled by patients.

Another issue identified by the studies was that where patients were followed up over time - patients had the potential to move home address ([27], [59]). It was argued by some studies that grouping distances into large categorical bands allowed patients to move residence, but not actually move categories during the study (e.g. Thompson et al.[65], whereby 27% of the study's population changed their residence during the 5 year follow up, but 91% of the patients had remained in the original distance category).

The majority of studies focused on one destination (e.g. hospital attended), for one type of treatment (e.g. an operation). This has the potential to underestimate the impact of distance/ travel times on health

[1] It is noted that not all patient journeys start from the patient's home address. This is therefore a proxy measure.

outcomes – where patients are potentially making multiple trips to a range of hospitals over the course of the year for a range of health issues. In an attempt to be more representative of the travel burden, Brewer et al.[19] used the follow up radiation centre address as the destination for patients rather than the place they had the surgery, as they argued patients would have to make this journey more frequently. Studies such as Jones et al.[37] considered the impact of a range of potential healthcare settings (e.g. distance to the nearest cancer centre, GP, hospital of first referral). They found a significant association between distance and survival for the GP, but not the other healthcare settings studied. Similarly, Wang et al. [58] found that as travel times to the nearest GP increased, patients were more likely to have a later stage breast cancer diagnosis, which was not evident when focusing on the distance to the nearest mammography service. These examples imply that focusing on a single site healthcare location (e.g. hospital where the surgery took place) could be missing the location that most influenced the patient health outcomes.

Measuring distance and travel time

Straight-line distance was used to calculate the distance for >25% of the studies. It is unlikely that any healthcare trip can be made in a straight – line, but it was argued by some studies that grouping distances into categories that covered large geographical areas, reduced the effects of differences between using road distance and straight-line distance. The remainder of the studies calculated travel time or road network based distance (either shortest route or quickest route). This was calculated in a variety of ways including making use of specific GIS software (e.g. ESRI ArcGIS, MAPINFO, ARCinfo), but more recent papers had used online routing websites such as Google Maps, www.Mellisa.com or www.Mapquest.com. Online resources are straightforward to use and highly accessible to calculate distances and travel times, but there is a question as to whether patient data (e.g patients home addresses and the hospital attended) should be uploaded to such websites and how secure this is, especially in the case of rarer diseases. A number of studies did take account of the time of year to control for potential differences in the weather and the impact this might have ([101]), but none included traffic congestion to calculate the travel times, which could significantly have increased the travel times included.

Distances and travel times were included in the statistical models as continuous or categorical variables or both separately. Studies identified that distances/ travel times tended to be positively skewed towards more patients living closer to the healthcare facilities that they were attending. In order to better represent this phenomenon Haynes et al.[34] split the travel times into categories according to the lowest quartile, medium (quartile 2 and 3), high (75th –95th percentile) and highest (95th– 100th percentile) categories. Other studies linearized distance/ travel time from the natural scale to the log scale, but the majority did not. For studies that included distance/ travel times as a categorical variable there was no consensus on what categories should be used. Study examples include, Sauerzapf, et al. [111]who split the travel distances into < 30 miles, 30 – 60 miles and > 60miles, Panagopoulou et al.[49] used dichotomous categories < 300km and > 300km, Littenberg, et al. [69] split data into < 10 km and ≥ 10 km and Allen et al. [82] calculated the mean distance and used this to split the data into two groups. Other studies used quartiles or quintiles. In many cases no justification was given for how the categories were determined, which has the potential to hide effects, where critical thresholds are missed. What the studies did identify was that the results were sensitive to the cut offs used in the model. Athas et al [17] found that after adjusting for age the likelihood of receiving radiotherapy following breast conserving surgery decreased significantly with increasing travel distance to the nearest facility for distances >74.9miles compared to <10miles, but not for categories in-between. In this case a dichotomous threshold that compared < 30 and ≥ 30 might not have picked up this effect. Studies maybe advised to undertake sensitivity analysis around the reference distance groups and categories used in their models – as this may greatly influence the results. Abou – Nassar et al. [14] and Maheswaran et al. [45] presented results that were only significant in the model that treated distance as a continuous variable; again the categories might not have been sensitive enough to pick up any effect.

Mode of transport

It was assumed in the majority of studies that patients would travel by car although there were exceptions (e.g. [81], [83], [64]). For some patients (potentially in the most deprived groups) it will not be possible to access healthcare by car. Moist et al.[64] reported that increased public transport travel time for patients contributed to missing kidney dialysis sessions. Jennings et al[76] reported that public transport travel times were longer for patients who did not attend follow up appointments compared to those that did. Other studies included public transport access through proxy measures (e.g. whether patients were within 800m walking distance of an hourly bus service). Issues with this include that it does not account for whether the bus service identified goes to the hospital, the travel time once on the bus or the likelihood of the patient being able to walk 800m. In one study, a travel survey of patients trips to the hospital found that 87% were made by car (Crawford et al. [103]). To ensure representative travel times/ distance it is critical to understand the patient population (in this case how they are travelling).

Key Relationships

The studies in the review highlight some of key factors that were found to be more sensitive to the distance decay effect. For example Joseph and Boeckh [80] identified that the distance decay effect was more pronounced for less serious illnesses, Arcury et al. [83] that patients attended significantly more regular check-up care visits the shorter the distance to the facility. Whilst for Lara et al. [77] distance was a predictive factor for not attending *in-between* follow up appointments (6 and 9 months), whereas it was not predictive for the 12 month or 3 month follow up appointments following a gastric band being fitted. These studies all suggest that when patients feel the health situation is more serious or they live closer they are more likely to attend. In their study Abbou_Nassar et al.[14] found that the impact of distance on health outcomes was only significant 1 year after a transplant suggesting that the point at which the health outcome and distance is measured could be critical to the results. Lake et al.[91] identified that whilst there was an effect of distance on patients attending treatment for TB, when doing sub-group analysis this was only significant for those patients not native to the country, so potentially identifying an impact of reduced ability to travel for patients who are less familiar with the healthcare system and transport network. All of which could be considered when tailoring healthcare provision and require further research.

One of the key influencing variables identified by the studies was deprivation. Dejardin et al. [27] found that when controlling for deprivation that the effect of distance on health outcomes was removed, whilst Crawford et al. [26] that distance amplified the effect from deprivation. From one side it might be argued that by controlling for deprivation this is also removing some of the impact of distance/ time that is experienced by those who do not have access to a car and would have to travel by other means. For those studies in the review not controlling for deprivation may be overestimating the true impact of distance travelled/ travel time on patient's health.

Studies such as those in table 3 (distance bias association) show that in some cases patients are able to travel longer distances and have better health outcomes than those living closer. This indicates that there are factors other than distance (such as deprivation) that are contributing to how easily patients can travel to access the healthcare facilities. Differences in distances that patients would be willing to travel (travel thresholds) to the primary care practice have been explored in studies such as Mcgrail et al. [120] who asked patients "what would be the maximum distance they would be willing to travel to access their GP? " (for a non-emergency). Communities where the population was sparsely located were found to be willing to travel a maximum of 22.2 minutes more to visit the primary care practice than those in closely settled communities. Buzza et al [121] found that distance was the most important barrier to accessing healthcare in their study, but also identified "health status, functional impairment, travel costs and work or family obligation" as key barriers (p648). Similarly the Social Exclusion Unit in the UK proposed that a person's ability to travel was influenced by key factors including their *travel horizons* (where are they willing to travel to?, What maximum distance? and do they have full awareness of available transport options for the journey), *Cost* (Can they afford to travel to the healthcare facility?), *Physical Access* (their health state may make accessing transport physically difficult or if accessing public transport there may not be an appropriate route) and *Crime* (they may not want to travel unless they felt safe making the journey) SEU [122]. All these factors need to be considered when focusing on where to locate a healthcare facility / improve access for patients to an existing facility) and ultimately improve health outcomes. For studies such as Bristow et al. [96] closer investigation of those patients living , <5km from the hospital whose health outcomes were worse than those living further away, or in the case of Kim et al. [42] what makes those patients living 20 – 30 km away have better health outcomes – what makes them different? And how can these other groups be better supported to access healthcare services? Using the types of studies brought together in this review allows some of these questions to be explored and inform debate over potential solutions.

The reason for undertaking this review was to collate and review evidence on the potential impact of distance and travel time to healthcare on patients' health outcomes. This is particularly pertinent given the move to centralised specialist services which typically means increased travel distance to access those healthcare facilities. Studies such as Kerschbaumer, et al. [41] have shown that if follow up can be completed successfully at a local level (even if the surgery is centralised) this can improve health outcomes and reduced travel burden. The review has shown that by making use of ex-post healthcare data providers can identify spatially pockets of patients who would be disadvantaged through having to travel further to access healthcare facilities and could use this to examine how these patients match with existing support and transport networks. It has also shown that it is not just about identifying patients who have to travel the furthest with evidence of patients living in close proximity to the healthcare facilities often fairing the worst. More research is needed to pick up on these factors and to explore in more detail the impact that the methods and data sources have on the results.

Strengths and Limitations

This systematic review has for the first time synthesised available evidence on the association between differences in travel time/distance to healthcare services and patient's health outcomes. It has identified a wealth of studies and generated evidence for wide range of disease groups and health outcomes, across multiple countries. There was great variation in study design, distances and travel times to the healthcare setting, and range of health outcomes; this precluded pooling of data for meta-analysis. The study followed a search strategy to maximise the identification of relevant studies of which 19 did not find an association between distance/ travel time and health outcomes; this is likely to be an underrepresentation if authors have a tendency to not publish results that showed no effect. While the review findings are of undoubted value in broadening our understanding of the wider societal factors that influence health outcomes, their applicability may be limited to countries with similar healthcare systems.

CONCLUSIONS

In the debate between local versus centralised healthcare provision, 77% of the included studies showed evidence of an association between worse health outcomes the further a patient lived from the healthcare facilities they needed to attend. This was evident at all levels of geography – local level, interurban and inter country level. A distance decay effect cannot be ruled out and distance/ travel time should be a consideration when configuring the locations of healthcare facilities and treatment options for patients.

Footnotes

Contributors: CK wrote the protocol with critical input from CH, GC, and TF. CK developed the search strategy and did the electronic searches. CK and CH screened the titles and abstracts and selected studies for inclusion. CK and CH carried out the data extraction and quality assessment. CK wrote the original draft and CH, GC and TF revised the draft critically for important intellectual content and approved the final version of the paper.

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REFERENCES

1. Woo Y, Kyrgiou M, Bryant A, et al. Centralisation of care may prolong survival in women with ovarian cancer and possibly more generally gynecological cancer. Secondary Centralisation of care may prolong survival in women with ovarian cancer and possibly more generally gynecological cancer 2012. http://summaries.cochrane.oorg/CD007945/centralisation-of -care-may-prolong-survival-inwomen-with-ovarian-cancer-and-possible-more-generally-gynaecological-cancer.

2. Morris S, Hunter RM, Ramsay AIG, et al. Impact of centralising acute stroke services in English metropolitan areas on mortality and length of hospital stay: difference-in-differences analysis. Bmj 2014;**349**.

3. Haynes R. Geographical access to healthcare. In: Guilliford M, Morgain M, eds. Access to Healthcare. London, 2003:13-35.

4. Goddard M, Smith P. Equity of access to healthcare. York: Centre for Health Economics. Secondary Equity of access to healthcare. York: Centre for Health Economics 1998. https://www.york.ac.uk/che/pdf/op32.pdf.

5. Hunter J, Shannon G. Jarvis revisited: Distance decay in service areas of mid - 19th century asylums. The professional Geographer 1985;**37**(3):296 - 302.

6. Khan A. An integrated approach to measuring potential spatial access to healthcare services. Socioecon Plann Sci 1992;**26**:275-87.

7. Jackson KL, Glasgow RE, Hill BR, et al. Does Travel Distance Influence Length of Stay in Elective Colorectal Surgery? Dis Colon Rectum 2013;**56**(3):367-73.

8. DeNino WF, Osler T, Evans EG, et al. Travel distance as factor in follow-up visit compliance in postlaparoscopic adjustable gastric banding population. Surg 2010;**6**(6):597-600.

9. Hansen W. How accessibility shapes land use. Journal of the American Institute of Planners 1959;**25**(2):73-76.

10. Lou W, Wang F. Measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. Environment and Planning B-Planning & Design 2003;**30**:865-84.

11. McGrail MR, Humphreys JS. Measuring spatial accessibility to primary care in rural areas: iproving the effectiveness of the two-step floating catchment area method. Applied Geography 2009;**29**(4):553-41.

12. Sackett D, Richardson W, Rosenberg W, et al. *Evidence -based medicine: how to practice and teach EBM.* . New York: Churchill Livingston, 1997.

13. CASP. Critical Appraisal Skills Programme. Secondary Critical Appraisal Skills Programme 2015. www.casp-uk.net/.

14. Abou-Nassar KE, Kim HT, Blossom J, et al. The Impact of Geographic Proximity to Transplant Center on Outcomes after Allogeneic Hematopoietic Stem Cell Transplantation. Biology of Blood and Marrow Transplantation 2012;**18**(5):708-15.

15. Albornoz CR, Cohen WA, Razdan SN, et al. The Impact of Travel Distance on Breast Reconstruction in the United States. Plastic and Reconstructive Surgery 2016;**137**(1):12-18.

16. Anderson AE, Henry KA, Samadder NJ, et al. Rural vs Urban Residence Affects Risk-Appropriate Colorectal Cancer Screening. Clinical Gastroenterology and Hepatology 2013;**11**(5):526-33.

17. Athas W, Adams-Cameron M, Hunt W, et al. Travel Distance to Radiation Therapy and Receipt of Radiotherapy Following Breast-Conserving Surgery. J Natl Cancer Inst 1999;**92**(3):269-72.

18. Baade PD, Dasgupta P, Aitken JF, et al. Distance to the closest radiotherapy facility and survival after a diagnosis of rectal cancer in Queensland. Med J Aust 2011;**195**(6):350-4.

19. Brewer N, Pearce N, Day P, et al. Travel time and distance to health care only partially account for the ethnic inequalities in cervical cancer stage at diagnosis and mortality in New Zealand. Australian and New Zealand Journal of Public Health 2012;**36**(4):335-42.

20. Bristow RE, Chang J, Ziogas A, et al. Spatial analysis of adherence to treatment guidelines for advanced-stage ovarian cancer and the impact of race and socioeconomic status. Gynecol Oncol 2014;**134**(1):60-67.

21. Burmeister BH, Zarate DD, Burmeister EA, et al. Lung cancer patients in Queensland suffer delays in receiving radiation therapy - but not as a result of distance. Intern Med J 2010;**40**(2):126-32.

22. Campbell N, Elliott A, Sharp L. Rural and urban differences in stage at diagnosis of colorectal and lung cancers. Br J Cancer 2001;**84**(7):910-4.

23. Campbell N, Elliott A, Sharp L, et al. Rural factors and survival from cancer: analysis of Scottish cancer registrations. Br J Cancer 2000;**82**(11):1863-6.

24. Celaya MO, Rees JR, J.J. G. Travel distance and season of diagnosis affect treatment choices for women with early stage breast cancer in a predominantly rural population. Cancer causes & control : CCC 2006;**17**(6):851-6.

25. Cramb SM, Mengersen KL, Turrell G, et al. Spatial inequalities in colorectal and breast cancer survival: premature deaths and associated factors. Health Place 2012;**18**(6):1412-21.

26. Crawford SM, Sauerzapf V, Haynes R, et al. Social and geographical factors affecting access to treatment of lung cancer. Br J Cancer 2009;**101**(6):897-901.

27. Dejardin O, Jones AP, Rachet B, et al. The influence of geographical access to health care and material deprivation on colorectal cancer survival: Evidence from France and England. Health and Place 2014;**30**:36-44.

28. Dupont-Lucas C, Dejardin O, Dancourt V, et al. Socio-geographical determinants of colonoscopy uptake after faecal occult blood test. Dig Liver Dis 2011;**43**(9):714-20.

29. Engelman K, Hawley D, Gazaway R, et al. Impact of geographic barriers on the utilization of mammograms by older rural women. J Am Geriatr Soc 2002;**50**(1):62-68.

30. Fournel I, Cottet V, Binquet C, et al. Rural - Urban inequalities in colorectal adenoma detection rates in the general population. Ann Oncol 2010;**21**:vi57.

31. Giuliani O, Mancini S, Puliti D, et al. Patterns and determinants of receipt of follow-up mammography and/or clinical examination in a cohort of Italian breast cancer survivors. Breast Cancer Research and Treatment 2016;**158**(3):543-51.

32. Goyal S, Chandwani S, Haffty BG, et al. Effect of travel distance and time to radiotherapy on likelihood of receiving mastectomy. Ann Surg Oncol 2015;**22**(4):1095-101.

33. Haddad AQ, Singla N, Gupta N, et al. Association of Distance to Treatment Facility on Quality and Survival Outcomes After Radical Cystectomy for Bladder Cancer. Urology 2015;**85**(4):876-82.

34. Haynes R, Pearce J, Barnett R. Cancer survival in New Zealand: ethnic, social and geographical inequalities. Soc Sci Med 2008;**67**(6):928-37.

35. Holmes JA, Carpenter WR, Wu Y, et al. Impact of distance to a urologist on early diagnosis of prostate cancer among black and white patients. J Urol 2012;**187**(3):883-8.

36. Huang B, Dignan M, Han D, et al. Does distance matter? Distance to mammography facilities and stage at diagnosis of breast cancer in Kentucky. J Rural Health 2009;**25**(4):366-71.

37. Jethwa K, Settergren B, Berg B, et al. Association between travel distance to a comprehensive cancer center and breast cancer stage, treatment, and outcomes in a rural state. Cancer Prevention Research 2013;**1)**.

38. Jones AP, Haynes R, Sauerzapf V, et al. Travel times to health care and survival from cancers in Northern England. Eur J Cancer 2008;**44**(2):269-74.

39. Jones AP, Haynes R, Sauerzapf V, et al. Geographical access to healthcare in Northern England and post-mortem diagnosis of cancer. J Public Health (Oxf) 2010;**32**(4):532-37.

40. Jones A, Haynes R, Sauerzapf V, et al. Travel time to hospital and treatment for breast, colon, rectum, lung, ovary and prostate cancer. Eur J Cancer 2008;**44**(7):992-9.

41. Kerschbaumer J, Freyschlag CF, Bauer R, et al. Distance to the neurooncological center: a negative prognostic factor in patients with glioblastoma multiforme. An epidemiological study. Anticancer Res 2012;**32**(12):5515-9.

42. Kim YE, Gatrell AC, Francis BJ. The geography of survival after surgery for colo-rectal cancer in southern England. Social Science and Medicine 2000;**50**(7-8):1099-107.

43. Lavergne MR, Johnston GM, Gao J, et al. Variation in the use of palliative radiotherapy at end of life: examining demographic, clinical, health service, and geographic factors in a population-based study. Palliat Med 2011;**25**(2):101-10.

44. Lin CC, Bruinooge SS, Kirkwood MK, et al. Association Between Geographic Access to Cancer Care, Insurance, and Receipt of Chemotherapy: Geographic Distribution of Oncologists and Travel Distance. J Clin Oncol 2015;**33**(28):3177-+.

45. Maheswaran R, Pearson T, Jordan H, et al. Socioeconomic deprivation, travel distance, location of service, and uptake of breast cancer screening in North Derbyshire, UK. J Epidemiol Community Health 2006;**60**:208-12.

46. Meden T, St John -Larkin C, Hermes D, et al. Relationship between travel distance and utilization of breast cancer treatment in rural northern Michigan. JAMA - Journal of the American Medical Association 2002;**2287**(1):111.

47. Nattinger AB, Kneusel R, Hoffman R, et al. Relationship of distance from a radiotherapy facility and initial breast cancer treatment. J Natl Cancer Inst 2001;**93**(17).

48. Onitilo AA, Liang H, Stankowski RV, et al. Geographical and seasonal barriers to mammography services and breast cancer stage at diagnosis. Rural and Remote Health 2014;**14**(3).

49. Panagopoulou P, Gogas H, Dessypris N, et al. Survival from breast cancer in relation to access to tertiary healthcare, body mass index, tumor characteristics and treatment: a Hellenic Cooperative Oncology Group (HeCOG) study. Eur J Epidemiol 2012;**27**(11):857-66.

50. Punglia R, Weeks J, Neville B, et al. Effect of distance to radiation treatment facility on use of radiation therapy after mastectomy in elderly women. International Journal of Radiation Oncology Biology Physics 2006;**66**(1):56-63.

51. Schroen A, Brenin D, Kelly M, et al. Impact of patient distance to radiation therapy on mastectomy use in early-stage breast cancer patients. Journal of Clinical Oncology 2005;**23**(28):7074-80.

52. Scoggins JF, Ramsey SD, Jackson JC, et al. Cost effectiveness of a program to promote screening for cervical cancer in the Vietnamese-American population. Asian Pac J Cancer Prev 2010;**11**(3):717-22.

53. Temkin SM, Fleming SA, Amrane S, et al. Geographic disparities amongst patients with gynecologic malignancies at an urban NCI-designated cancer center. Gynecol Oncol 2015;**137**(3):497-502.

54. Thomas AA, Gallagher P, O'Ceilleachair A, et al. Distance from treating hospital and colorectal cancer survivors' quality of life: a gendered analysis. Supportive care in cancer : official journal of the Multinational Association of Supportive Care in Cancer 2015;**23**(3):741-51.

55. Tracey E, McCaughan B, Badgery-Parker T, et al. Survival of Australian lung cancer patients and the impact of distance from and attendance at a thoracic specialist centre: a data linkage study. Thorax 2015;**70**(2):152-60.

56. Tracey E, McCaughan B, Badgery-Parker T, et al. Patients with localized non-small cell lung cancer miss out on curative surgery with distance from specialist care. ANZ J Surg 2015;**85**(9):658-63.

57. Tracey E, Hacker NF, Young J, et al. Effects of Access to and Treatment in Specialist Facilities on Survival From Epithelial Ovarian Cancer in Australian Women A Data Linkage Study. Int J Gynecol Cancer 2014;**24**(7):1232-40.

58. Wang F, McLafferty S, Escamilla V, et al. Late-stage breast cancer diagnosis and health care access in illinois. Professional Geographer 2008;**60**(1):54-69.

59. Bello AK, Hemmelgarn B, Lin M, et al. Impact of remote location on quality care delivery and relationships to adverse health outcomes in patients with diabetes and chronic kidney disease. Nephrol Dial Transplant 2012;**27**(10):3849-55.

60. Bello AK, Wiebe N, Hemmelgarn BR, et al. A population-based study on care and clinical outcomes in remote dwellers with heavy proteinuria. Kidney International Supplements 2013;**3**(2):254-58.

61. Cho Y, Badve SV, Hawley CM, et al. The effects of living distantly from peritoneal dialysis units on peritonitis risk, microbiology, treatment and outcomes: a multi-centre registry study. Bmc Nephrology 2012;**13**.

62. Judge A, Caskey FJ, Welton NJ, et al. Inequalities in rates of renal replacement therapy in England: does it matter who you are or where you live? Nephrol Dial Transplant 2012;**27**(4):1598-607.

63. Miller LM, Vercaigne LM, Moist L, et al. The association between geographic proximity to a dialysis facility and use of dialysis catheters. Bmc Nephrology 2014;**15**.

64. Moist LM, Bragg-Gresham JL, Pisoni RL, et al. Travel time to dialysis as a predictor of health-related quality of life, adherence, and mortality: the Dialysis Outcomes and Practice Patterns Study (DOPPS). Am J Kidney Dis 2008;**51**(4):641-50.

65. Thompson S, Gill J, Wang X, et al. Higher mortality among remote compared to rural or urban dwelling hemodialysis patients in the United States. Kidney Int 2012;**82**(3):352-9.

66. Thompson S, Bello A, Wiebe N, et al. Quality-of-care indicators among remote-dwelling hemodialysis patients: a cohort study. Am J Kidney Dis 2013;**62**(2):295-303.

67. Tonelli M, Hemmelgarn B, Culleton B, et al. Mortality of Canadians treated by peritoneal dialysis in remote locations. Kidney Int 2007;**72**(8):1023-8.

68. Tonelli M, Manns B, Culleton B, et al. Association between proximity to the attending nephrologist and mortality among patients receiving hemodialysis. Cmaj 2007;**177**(9):1039-44.

69. Littenberg B, Strauss K, MacLean CD, et al. The use of insulin declines as patients live farther from their source of care: results of a survey of adults with type 2 diabetes. BMC Public Health 2006;**6**:198.

70. Strauss K, MacLean C, Troy A, et al. Driving distance as a barrier to glycemic control in diabetes. J Gen Intern Med 2006;**21**(4):378-80.

71. Zgibor J, Gieraltowski L, Tallbot E, et al. The association between driving distance and glycemic control in rural areas. Journal Diabetes Science and Technology 2011;**5**(3):494-500.

72. Goldberg DS, French B, Forde KA, et al. Association of distance from a transplant center with access to waitlist placement, receipt of liver transplantation, and survival among US veterans. Jama 2014;**311**(12):1234-43.

73. Redhage LD, Harms K, Moore DE, et al. Closer proximity to the transplant center is associated with better physical health-related quality of life after liver transplantation. Hpb 2013;**15**:65-66.

74. Thabut G, Munson J, Haynes K, et al. Geographic Disparities in Access to Lung Transplantation Before and After Implementation of the Lung Allocation Score. Am J Transplant 2012;**12**(11):3085-93.

75. Zorzi D, Rastellini C, Freeman DH, et al. Increase in mortality rate of liver transplant candidates residing in specific geographic areas: analysis of UNOS data. Am J Transplant 2012;**12**(8):2188-97.

76. Jennings N, Boyle M, Mahawar K, et al. The relationship of distance from the surgical centre on attendance and weight loss after laparoscopic gastric bypass surgery in the United Kingdom. Clinical Obesity 2013;**3**(6):180-84.

77. Lara MD, Baker MT, Larson CJ, et al. Travel distance, age, and sex as factors in follow-up visit compliance in the post-gastric bypass population. Surg 2005;**1**(1):17-21.

78. Sivagnanam P, Rhodes M. The importance of follow-up and distance from centre in weight loss after laparoscopic adjustable gastric banding. Surgical Endoscopy and Other Interventional Techniques 2010;**24**(10):2432-38.

79. McCarthy JF, Blow FC, Valenstein M, et al. Veterans Affairs Health System and mental health treatment retention among patients with serious mental illness: evaluating accessibility and availability barriers. Health Serv Res 2007;**42**(3 Pt 1):1042-60.

80. Joseph AE, Boeckh JL. Locational variation in mental health care utilization dependent upon diagnosis: A Canadian example. Social Science and Medicine - Part D Medical Geography 1981;**15**(3):395-404.

81. Skarsvag K, Wynn R. Travel Time and the Use of Psychiatric Outpatient Clinic Services in Coastal Northern Norway [4]. Canadian Journal of Psychiatry 2004;**49**(2):153-54.

82. Allen A, Amram O, Tavakoli H, et al. Relationship between Travel Time from Home to a Regional Sleep Apnea Clinic in British Columbia, Canada, and the Severity of Obstructive Sleep. Annals of the American Thoracic Society 2016;**13**(5):719-23.

83. Arcury TA, Preisser JS, Gesler WM, et al. Access to transportation and health care utilization in a rural region. J Rural Health 2005;**21**(1):31-8.

84. Ballard DJ, Bryant SC, O'Brien PC, et al. Referral selection bias in the Medicare hospital mortality prediction model: are centers of referral for Medicare beneficiaries necessarily centers of excellence? Health Serv Res 1994;**28**(6):771-84.

85. Chou S, Deily ME, Li S. Travel distance and health outcomes for scheduled surgery. Med Care 2014;**52**(3):250-7.

86. Etzioni DA, Fowl R, Wasif N. Distance Bias and Surgical Outcomes. Med Care 2013;**51**:238-44.

87. Evans EE, Wang XQ, Moore CC. Distance from care predicts in-hospital mortality in HIV-infected patients with severe sepsis from rural and semi-rural Virginia, USA. Int J STD AIDS 2016;**27**(5):370-76.

88. Haynes R, Bentham G, Lovett A, et al. Effects of distances to hospital and GP surgery on hospital inpatient episodes, controlling for needs and provision. Soc Sci Med 1999;**49**(3):425-33.

89. Jackson KL, Glasgow RE, Mone MC, et al. Does travel distance influence length of stay in elective pancreatic surgery? Hpb 2014;**16**(6):543-49.

90. Jones AP, Bentham G, Horwell C. Health service accessibility and deaths from asthma. Int J Epidemiol 1999;**28**(1):101-5.

91. Lake IR, Jones NR, Bradshaw L, et al. Effects of distance to treatment centre and case load upon tuberculosis treatment completion. Eur Respir J 2011;**38**(5):1223-5.

92. Lankila T, Nayha S, Rautio A, et al. Is geographical distance a barrier in the use of public primary health services among rural and urban young adults? Experience from Northern Finland. Public Health 2016;**131**:82-91.

93. Monnet E. Socioeconomic context, distance to primary care and detection of hepatitis C: a French population-based study.

94. Prue DM, Keane TM, Cornell JE, et al. An analysis of distance variables that affect aftercare attendance. Community Ment Health J 1979;**15**(2):149-54.

95. Singh D, Jaiswal V, Sonkar AA, et al. Randomized control trial of conventional laparoscopic versus single incision laparoscopic cholecystectomy. Hpb 2014;**16**:115.

96. Bristow RE, Chang J, Ziogas A, et al. Spatial analysis of advanced-stage ovarian cancer mortality in California. American Journal of Obstetrics and Gynecology 2015;**213**(1).

97. Lamont EB, Hayreh D, Pickett KE, et al. Is patient travel distance associated with survival on phase II clinical trials in oncology? J Natl Cancer Inst 2003;**95**(18):1370-75.

98. Lenhard Jr RE, Enterline JP, Crowley J, et al. The effects of distance from primary treatment centers on survival among patients with multiple myeloma. Journal of clinical oncology : official journal of the American Society of Clinical Oncology 1987;**5**(10):1640-45.

99. Lipe BC, Lansigan F, Gui J, et al. Bone marrow transplant for multiple myeloma: impact of distance from the transplant center. Clin 2012;**10**(1):28-32.

100. Wasif N, Pockaj BA, Gray RJ, et al. Distance travelled is an unrecognized bias for short and longterm outcomes following complex gastrointestinal cancer surgery: Results from the national cancer database. Ann Surg Oncol 2014;**1)**:S28.

101. Celaya MO, Berke EM, Onega TL, et al. Breast cancer stage at diagnosis and geographic access to mammography screening (New Hampshire, 1998-2004). Rural Remote Health 2010;**10**(2):1361.

102. Cosford P, Garrett C, Turner K. Travel times and radiotherapy uptake in two English counties. Public Health 1997;**111**(1):47-50.

103. Crawford SM, Sauerzapf V, Haynes R, et al. Social and geographical factors affecting access to treatment of colorectal cancer: a cancer registry study. Bmj Open 2012;**2**(2).

104. Gunderson CC, Nugent EK, McMeekin DS, et al. Distance traveled for treatment of cervical cancer: who travels the farthest, and does it impact outcome? Int J Gynecol Cancer 2013;**23**(6):1099-103.

105. Heelan K, McKenna D. Distance to specialist services and relationship to Breslow thickness at presentation of patients with malignant melanoma. J Am Acad Dermatol 2011;**1)**:AB118.

106. Henry KA, Sherman R, Farber S, et al. The joint effects of census tract poverty and geographic access on late-stage breast cancer diagnosis in 10 US States. Health Place 2013;**21**:110-21.

107. Henry K, Boscoe FP, Johnson C, et al. Breast cancer stage at diagnosis: is travel time important? J Community Health 2011;**36**(6):933-42.

108. Khera N, Gooley T, Flowers MED, et al. Association of Distance from Transplantation Center and Place of Residence on Outcomes after Allogeneic Hematopoietic Cell Transplantation. Biology of Blood and Marrow Transplantation 2016;**22**(7):1319-23.

109. Meersman SC, Breen N, Pickle LW, et al. Access to mammography screening in a large urban population: a multi-level analysis. Cancer Causes Control 2009;**20**(8):1469-82.

110. Ragon BK, Clifton C, Chen H, et al. Geographic Distance Is Not Associated with Inferior Outcome When Using Long-Term Transplant Clinic Strategy. Biology of Blood and Marrow Transplantation 2014;**20**(1):53-57.

111. Sauerzapf V, Jones A, Haynes R, et al. Travel time to radiotherapy and uptake of breast-conserving surgery for early stage cancer in Northern England. Health Place 2008;**14**(3):424-33.

112. Schroen A, Lohr M. Travel Distance to Mammography and the Early Detection of Breast Cancer. The Breast Journal 2009;**15**(2):216-17.

113. Firozvi AA, Lee CH, Hayashi PH. Greater travel time to a liver transplant center does not adversely affect clinical outcomes. Liver Transpl 2008;**14**(1):18-24.

114. Leese GP, Feng Z, Leese RM, et al. Impact of health-care accessibility and social deprivation on diabetes related foot disease. Diabet Med 2013;**30**(4):484-90.

115. Markin CJ, Roessel LL, Lai GP, et al. Does geographic distance from a pulmonary hypertension center delay diagnosis and treatment? A REVEAL registry analysis. Journal of Heart and Lung Transplantation 2011;**1)**:S14.

116. Rodkey SM, Hobbs RE, Goormastic M, et al. Does distance between home and transplantation center adversely affect patient outcomes after heart transplantation? Journal of Heart and Lung Transplantation 1997;**16**(5):496-503.

117. Stoller JK, Sandhaus RA, Turino G, et al. Delay in diagnosis of alpha1-antitrypsin deficiency: A continuing problem. Chest 2005;**128**(4):1989-94.

118. Swan-Kremeier LA, Mitchell JE, Twardowski T, et al. Travel distance and attrition in outpatient eating disorders treatment. Int J Eat Disord 2005;**38**(4):367-70.

119. Tonelli M, Klarenbach S, Manns B, et al. Residence location and likelihood of kidney transplantation. Can Med Assoc J 2006;**175**(5):478-82.

120. McGrail M, Humphreys J, Ward B. Accessing doctors at times of need-measuring the distance tolerance of rural residents for health-related travel. BMC Health Serv Res 2015;**29**(15):212.

121. Buzza C, Ono SS, Turvey C, et al. Distance is relative: unpacking a principal barrier in rural healthcare. J Gen Intern Med 2011;**26 Suppl 2**:648-54.

122. Social Exclusion Unit. Making the connections: Final report on transport and social exclusion. London, 2003.

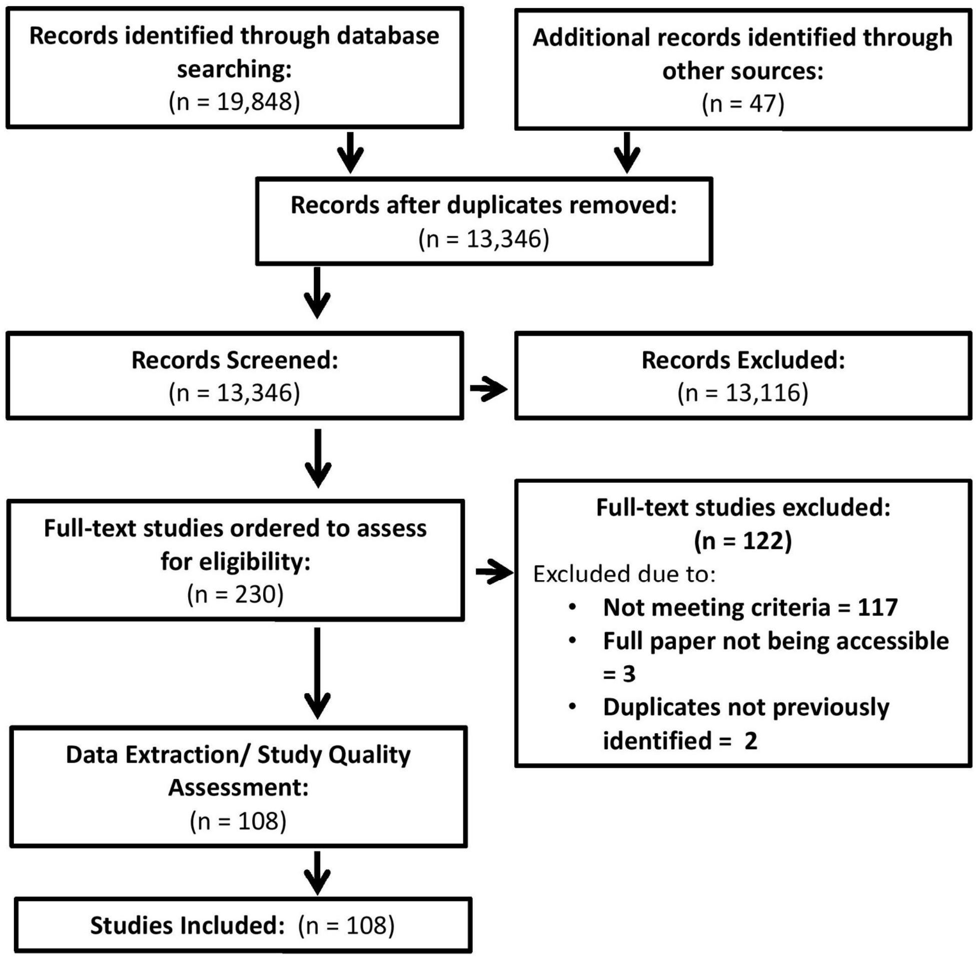

Figure 1: Flow Diagram of Papers
Figure 1
180x179mm (300 x 300 DPI)

Supplementary file 1: Search Terms for MEDLINE

Intervention/ Comparator terms	**Population accessing Healthcare**	**Health Outcomes**
Proximity adj3 health*.ti,ab	health*adj3 access*.ti,ab	Health status.ab,ti
Proximity adj3 hospital*.ti,ab	health* adj3 care.ti,ab	Health inequal*.ab,ti
Travel*.ab,ti	health* adj3 facilit*.ti,ab	"health related quality of life".ab,ti
Distance*.ab,ti	hospital*.ti,ab	Hrqol.ab,ti
Patient adj3 transport.ti,ab	inpatient*.ab,ti	Mortality.ab,ti
Journey*adj5 (car or bus or transit or transport* or public transport or train).ti,ab	outpatient*.ti.ab	Delay* adj3 diagnosis.ab,ti
Time to hospital*.ab,ti	health* adj3 appoint*.ab,ti	Late* adj3 diagnosis.ab,ti
Transportation of patients/	rural adj3 health*.ab.ti	Miss*adj3 appoint*.ab,ti
Travel/	urban adj3 health*.ab,ti	Health adj3 outcome.ab,ti
	communit* adj3 health*.ti,ab	Quality of life.ab,ti
	primary health*.ab,ti	Self reported health.ab,ti
	family practice.ab,ti	Prognosis.ab,ti
	gen* pract*.ab,ti	Complete adj3 treatment.ab,ti
	health* adj3 screen*.ti,ab	Did not attend.ab,ti
	clinic.ab,ti or clinics.ab,ti	Health status/ or health status disparities/
	GP.ab,ti	*"Quality of life"/ or patient compliance/ or patient refusal/ or diagnosis/ or delayed diagnosis/
	"accident and emergency".ab,ti	Mortality/
	health services accessibility/	Prognosis/

	hospitals/ or hospitals, community/ or hospitals, general/ or hospitals, group practice/ or hospitals, high-volume/ or hospitals, low-volume/ or hospitals, private/ or hospitals, public/ or hospitals, rural/ or hospitals, satellite/ or hospitals, special/ or hospitals, teaching/ or hospitals, urban/ or mobile health units/ or secondary care centers/ or tertiary care centers/Appointments and schedules/	Treatment adj3 retention.ab,ti
	Mass screening/	Treatment adj3 follow adj3 up.ab,ti
	Urban health/	Patient complian*.ab,ti
	Rural health/	
	Health services/ or primary healthcare/ or general practice/ or tertiary healthcare/	
	Emergency service, hospital/	

Restrictions	NOT exercise test/ or exercise test.ab,ti
	English Language

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	5-6
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	5
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	5
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	5
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	Supplementary Material 1
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5/6
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5/6
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	Tables 2 -4
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	Table 1 and page 6
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	n/a
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	Meta analysis not

PRISMA 2009 Checklist

			appropriate.

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	Table 1 (p7)
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	Figure 1 page 8
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	Tables 2 – 4
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	Summarised across studies – see #22 below
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	N/A
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	N/A
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	Table 1 p7
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	N/A
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	P40 - 48
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	P47-48
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	P48
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	P48

PRISMA 2009 Checklist

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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