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Observational cross-sectional study of the association of poor broadband provision with demographic and health outcomes: the Wolverhampton Digital ENablement (WODEN) programme

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ABSTRACT

Objectives The association between impaired digital provision, access and health outcomes has not been systematically studied. The Wolverhampton Digital ENablement programme (WODEN) is a multiagency collaborative approach to determine and address digital factors that may impact on health and social care in a single deprived multiethnic health economy. The objective of this study is to determine the association between measurable broadband provision and demographic and health outcomes in a defined population.

Design An observational cross-sectional whole local population-level study with cohorts defined according to broadband provision.

Setting/participants Data for all residents of the City of Wolverhampton, totalling 269 785 residents.

Primary outcomes Poor broadband provision is associated with variation in demographics and with increased comorbidity and urgent care needs.

Results Broadband provision was measured using the Broadband Infrastructure Index (BII) in 158 City localities housing a total of 269 785 residents. Lower broadband provision as determined by BII was associated with younger age ($p<0.001$), white ethnic status ($p<0.001$), lesser deprivation as measured by Index of Multiple Deprivation ($p<0.001$), a higher number of health comorbidities ($p<0.001$) and more non-elective urgent events over 12 months ($p<0.001$).

Conclusion Local municipal and health authorities are advised to consider the variations in broadband provision within their locality and determine equal distribution both on a geographical basis but also against demographic, health and social data to determine equitable distribution as a platform for equitable access to digital resources for their residents.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This is the first study to link data on broadband provision to health data at a defined health economy population level.
- ⇒ Our observational study used a high-quality dataset from the local population that has been used in other research studies.
- ⇒ Our study methodology, which is generalisable, enables assessment of the importance of evaluation at the local level considering local population variations, perhaps lost at the inter-regional or national level.
- ⇒ The study is limited by being observational and cross-sectional rather than interventional or prospective.
- ⇒ The study does not have individual-level socioeconomic data, nor an individual assessment of digital access, use or competency.

INTRODUCTION

The very rapid integration of digital technology into the delivery of healthcare has been accelerated by COVID-19.[1 2] Driven by the pandemic, the adaptability of healthcare providers to replace 'face-to-face' consultations with technology-based remote access services has been truly commendable. However, such digital services may not have been accessible to all service users. Clearly recognised access barriers are a user's ability to engage with technology and their digital illiteracy[2] but others include limited access to any required equipment, broadband connectivity and internet access. Such infrastructure considerations may well be equally fundamental to digital healthcare service access. All such factors are broadly recognised as the digital determinants of health.[1]

There is a need to ensure that service users are not excluded as a result of historical, current and future strategies which will drive digital transformations to healthcare.[3–5] Identifying those with digitally driven access barriers, and ensuring that services are flexed to provide equity of care to them, is important both to avoid direct clinical risk to their management and to prevent a widening of societal health inequalities.[6–11] Such associations have raised the spectre of creating a digital underclass.[8 9 12]

Accordingly, the play of the digital determinants at the individual or group level are increasingly being considered[4 13 14] but that does not seem to have led to a clear or systematic approach at the level of healthcare economies. Healthcare authorities will increasingly need to develop a more comprehensive understanding of population-level needs and shift resources accordingly. Even then, it is not clear that we have the evidence-based assessments to inform such decision making and such tools that exist are generally applied to individuals. This evidence is usually gathered through questionnaires that have variable validity and are limited by small sample sizes or are conducted on discrete groups,[15] often those with standing digital access.

Wolverhampton is a UK City functioning as a single health and social care economy with a population of circa 270 000. It is multiethnic and socioeconomically deprived.[16] The Wolverhampton Digital Enablement (WODEN) programme is a multiagency collaborative approach to determine and address digital factors that may impact on health and social care. The aim of this study was to focus on broadband provision and to consider, at population scale, its association with demography and with key health outcomes. Published research that systematically analyses the association between impaired digital access with health outcomes is very limited. As far we can determine, our methodology is novel, and any independent association with adverse health outcome, while intuitively expected, has never been systematically determined.

METHODS

Population studied

All patients, including children and young people, registered with a Wolverhampton general practitioner (GP) and those who were residents known to have had any hospital contact.

Data

Individual data were anonymised. To identify the link between broadband provision, demographic and health outcomes, a single dataset was developed by merging the Point Topic Broadband Digital Exclusion[17] and the Wolverhampton Integrated Healthcare databases using post codes to which local authority area codes for the lower layer super output areas (LLSOAs) are mapped. LLSOAs describes a geographical breakdown of the UK, with an average population of 1500 people or 650 households, and are widely used to improve the reporting of small populations in National Health Service (NHS) data modelling.[18]

The Wolverhampton Integrated Healthcare database

The Wolverhampton integrated healthcare database is a database developed to integrate data from primary care, community and hospital clinical and pathology systems, for the residents of Wolverhampton, and from immediately adjacent districts, for all people residing in Wolverhampton or registered to Wolverhampton practices, and from immediately adjacent districts with emergency admission to New Cross Hospital, using methodology we have previously described.[19]

The demographic and healthcare variables extracted were age, gender, ethnicity, the Index of Multiple Deprivation (IMD) ranked score as determined from postcodes, long-term condition comorbidities and non-elective health activity. Ethnicity data from all sources were reviewed, only unambiguous data were accepted, then recoded into white, South-Asian, black, mixed ethnicity, Chinese or unknown. The sum of comorbidities in any individual was determined by the total number of comorbidities, which matched the long-term conditions found in the population, which are utilised in defining comorbidity in the local health economy 16 most common comorbidities. These are: asthma, atrial fibrillation, cancer, cardiovascular diseases, chronic kidney disease, chronic obstructive pulmonary disease, dementia, depression and other mental health disorder, diabetes, epilepsy, haemoglobinopathy, heart failure, hypertension, learning difficulties, osteoarthritis and rheumatoid arthritis. The sum of non-elective health activity events was determined by the number of emergency department attendances not leading to admission, plus the number of non-elective admissions over the preceding 12 months to our local hospital.

The point topic database and the identification of appropriate measure of broadband provision

The Point Topic system develops a global Broadband Digital Deprivation Index from a variety of variables including the Broadband Infrastructure Index (BII) but also the IMD summary score and other ranked measures derived from the IMD such as age, income and housing. The index is a ranked score for all English LLSOAs. The BII subcomponent was the variable selected as a measure of broadband infrastructure provision. The BII is an index measure representative of broadband provision including the type, speed and bandwidth quality and number of suppliers for broadband in those defined localities.[17 20] The BII assessment used is for the year 2020. Thus, within the merged dataset, there were a number of variables that might have shared common subcomponents and particular care was taken to ensure the independence of BII as a variable (presented in Results). We emphasise the BII to be a measure of provision, not access or uptake and, just as standard practice with the use of IMD, it defines the characteristic of a geographical unit, the LLSOA, not the individuals who may live in it.

Statistical method

All data were analysed on IBM SPPS V.26. When comparing independent groups, the Student's t-test and the χ^2 test were used for the difference between means

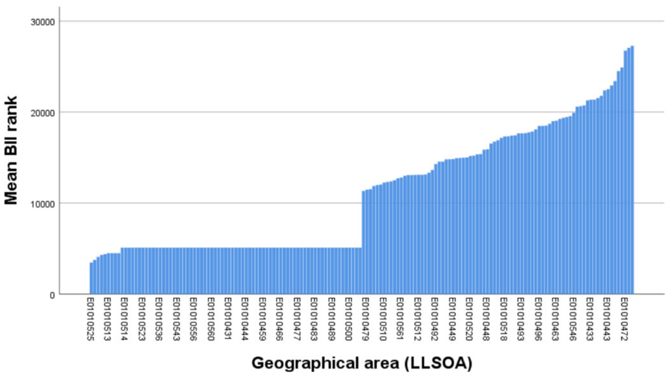

Figure 1 Demonstrating the dichotomised distribution of the Broadband Infrastructure Index (BII) and its suitability for binary logistic regression analysis. LLSOA, lower layer super output area.

and proportions, respectively. Principal components analysis (with rotation) was used when considering the interdependence of independent variables, especially in relationship to the BII.

The BII, an ordinal variable, was not normally distributed and clearly dichotomised into two groups above and below a rank value of 10 000 (figure 1). The purpose of this analysis was to define associations with the poorer provisioned broadband group with a BII of <10 000. Thus, binary logistic regression analysis was used to examine the relationship between BII as the dependent (dichotomised) variable and various independent variables. The continuous independent variables of IMD and age were categorised on the basis of quintiles and thus utilised as categorical variables. Comorbidities was categorised as those with a total sum comorbidity score less than three and a total sum score of greater than or equal to three. The independent variables were in two broad groupings (1) the demographic variables of age, gender, ethnicity and (2) variables of deprivation; the two health outcome variables of long-term condition comorbidity and of emergency non-elective urgent care. There is a known association and thus a potential confounding effect between these two independent variable groupings and this was negated in our analysis by taking a stepwise approach, entering each block separately as previously described.[21] The regression analysis was undertaken on 250 609 residents as 19 176 were excluded by missing or unclassifiable ethnicity coding. Results are presented as the mean±SD or as percentages. Statistical significance was taken at p<0.05.

Patient and public involvement

None as not applicable to this type of study.

RESULTS

Population and localities

The final cohort were the 269 785 alive at the point of data acquisition in the year 2020 and included 13 945 residents registered to a non-Wolverhampton GP (table 1). The datasets were linked on locality codes. There are 158 LLSOAs in Wolverhampton with a surface area of (mean±SD) (range) 0.44±0.28 (0.13–2.20) km^2, with 691±139 (466–1388) and 1708±435 (857–3476) households and individuals per locality, respectively. We again emphasise that IMD and BII data are derived from rankings relating to the locality codes and not from direct assessment of individuals, and we do not have individual socioeconomic data.

Table 1 Demographic and health data of the whole resident population, subdivided by categories of the Broadband Infrastructure Index (BII)

	Whole population n=269 785	BII <10 000 (worse) n=125 007 (46%)	BII>10 000 n=144 778 (54%)	P value
BII rank	11 657±6926	4971±348 (3451–5095)	17 430±4168 (11 328–27 276)	t=1053.6, p<0.001
Age (years)	38.6±23.2 (0–106)	39.1±23.3	38.3±23.0	t=8.816, p<0.001
Gender (male %)	50.4	50.1	50.6	χ^2 =4.45, p<0.05
Ethnicity white, %	57.1	65.6	57.9	χ^2 =1521.5, p<0.001
IMD score	34.7±15.9 (5.4–71.8)	32.6±15.6	36.4±15.8	t=63.549, p<0.001
IMD rank	8878±7872	9698±7739	8169±7916	t=50.586, p<0.001
Number of comorbidities	0.61±1.06 (0–11)	0.63±1.07	0.59±1.05	t=11.069, p<0.001
Any comorbidity, %	35	36.5	34	χ^2 =173.54, p<0.001
Number of non-elective contacts in 12 months	0.24±0.84 (0–65)	0.242±0.85	0.235±0.83	t=2.042, p<0.05
Any non-elective contact in 12 months	14.4%	14.7%	14.4%	χ^2 =16.01, p<0.001

Results are the mean±SD with (range), ns=non-significant and the p value is for the significance of the difference between the two BII categories.
IMD, Index of Multiple Deprivation.

The Broadband Infrastructure Index

The wider Broadband Digital Deprivation Index is derived from many variables including those related to deprivation. Thus, the correlation between IMD (as IMD rank score) and the global Broadband Digital Deprivation Index was tight and highly significant (r=0.902, p<0.001). In a principal component analysis, including all subsidiary variables, four components emerged (eigenvalue of ≥1), the BII subcomponent of the Broadband Digital Deprivation Index was independent of all other IMD indices apart from IMD housing rankings, which equally spanned the deprivation and BII components, which has face validity. Accordingly, the linear correlation between BII and IMD ranking was extremely weak (r=−0.16, p<0.001) with an r^2 of only 3%, confirming with high confidence that the two measures were independent. The BII component was therefore identified as an appropriate measure of broadband provision for linkage to health data at the LLSOA local authority area code levels. We emphasise BII not to be a continuous variable since the group was clearly divisible into two cohorts of those with a distinctly low BII versus others at a threshold rank score of 10 000 (figure 1).

The association between broadband provision, demographic and health outcomes

The demographic and health data of the whole population and of the BII groupings are shown in table 1. Regarding demography, the lower scoring BII group (lesser provision) were older and also had marginally more females. Of particular note, for the lesser provisioned BII category, both the IMD parameters indicated this group to be less, not more, deprived and they had a higher, not lower, white ethnicity prevalence. The crude relationship of the BII as a dichotomised group to quintiles of the IMD score (χ^2=7559.4, p<0.001), quintiles of age (χ^2=156.7, p<0.001) and with ethnicity (χ^2=1521.5, p<0.01) is depicted in figure 2. For parameters of health outcomes (table 1), the lower scoring BII group was significantly more comorbid as measured by the total number of comorbidities or by the proportion with any comorbidity and they had a very small but significant excess of non-elective urgent health activity over the preceding 12 months. Since BII is not a continuous variable, these factors were also entered into binary logistic regression of the dichotomised BII status as the dependent variable with the purpose of highlighting the magnitude, direction and significance of any association with the lower BII group of the defined independent variables which were entered in two stages: first, the demographic factors of quintiles of age, gender (male vs female), ethnicity (white vs other) and quintiles of the IMD score; second, comorbidity (any vs none) and urgent events (any vs none). Table 2 shows the outputs of this model which was highly significant (χ^2=7914.8, p<0.001), although the independent factors explained very little of the variance (r^2=0.042). At step 1, the

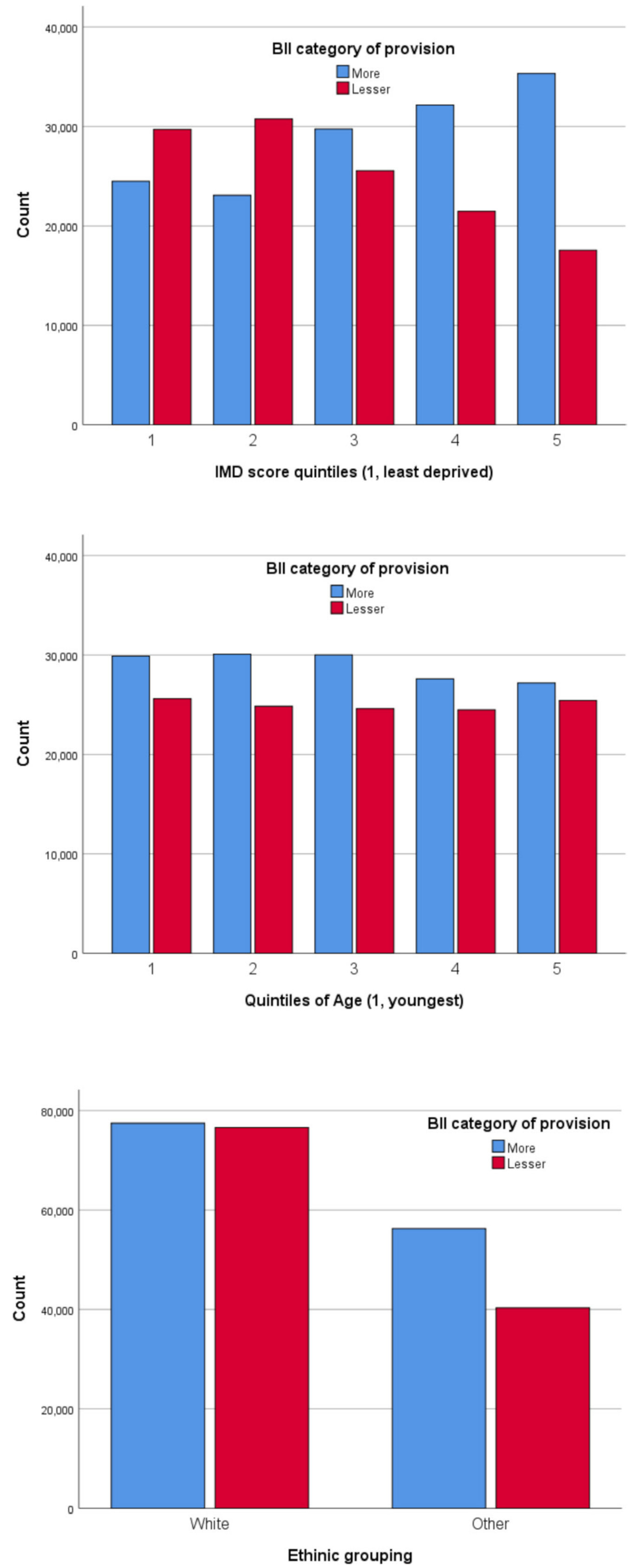

Figure 2 The crude relationships of IMD, age and Ethnicity to the category of the Broadband Infrastructure Index (BII). IMD, Index of Multiple Deprivation.

Table 2 Binary logistic regression identifying factors associated with the poor or least provisioned Broadband Infrastructure Index (BII) group

Variable	OR (95% CI)	P value
Step 1		
IMD Q1 (11.6±3.2) (least deprived)	2.14 (2.09 to 2.19)	<0.001
IMD Q2 (24.3±4.0)	2.37 (2.31 to 2.43)	<0.001
IMD Q3 (36.8±2.5)	1.38 (1.35 to 1.42)	<0.001
IMD Q4 (44.1±2.0)	1.27 (1.24 to 1.31)	<0.001
IMD Q5 (56.1±5.2) (most deprived)*	1.0	–
Age Q1 (7.7±4.5 years) (youngest)	1.20 (1.16 to 1.23)	<0.001
Age Q2 (24.0±4.7 years)	1.08 (1.05 to 1.11)	<0.001
Age Q3 (38.3±4.0 years)	1.08 (1.05 to 1.11)	<0.001
Age Q4 (52.8±4.3 years)	1.06 (1.03 to 1.09)	<0.001
Age Q5 (72.8±8.7 years) (oldest)*	1.0	–
White ethnicity (61.5%)	1.33 (1.31 to 1.36)	<0.001
Other ethnic groups*	1.0	
Step 2		
Any comorbidities present (35.2%)	1.07 (1.05 to 1.09)	<0.001
No comorbidities present*	1.0	
Any emergency episode (14.4%)	1.05 (1.03 to 1.08)	<0.001
No emergency episodes*	1.0	

The analysis was undertaken on 250 609 subjects with 19 176 missing cases due to a lack of ethnicity data. The ORs are for the poor or least provisioned BII group.
*Represents the reference group for each categorical variable from which all other groups in that variable were compared.
IMD, Index of Multiple Deprivation.

model adjusted Odds Ratios confirmed the crude associations with IMD (p<0.001) and ethnicity (p<0.001) but exposed a different (model adjusted) pattern for age (p<0.001) with the younger quintiles to be in the low scoring BII group while the association of gender was not significant. At step 2, the relationship of heath indices of any comorbidity (p<0.001) and any urgent care event (p<0.001) to low BII were both highly significant, noting these two latter variables to have a degree of correlation (χ^2=3719.4, η=0.12, p<0.001).

DISCUSSION

On the contention that physical availability of broadband infrastructure should not be overlooked as a precursor to healthcare access,[22] we aimed to identify the nature of association between broadband provision, population demographics and health outcomes in a single health economy, ours being deprived and multiethnic by UK standards. To our knowledge, this is the first study to identify a candidate measure of broadband provision (BII) and link it to population-level health data (urgent care and comorbidity) and indices of deprivation (IMD). In some sense, we wished to consider the epidemiology of broadband provision. We find that associations exist between BII determined broadband provision, demographic variables and health outcomes.

The derivation of the BII is described elsewhere.[17 20] Previous studies, to the best of our knowledge, have not identified or utilised any adequate measure of broadband infrastructure[13 23–25] and we are the first to demonstrate that it is essentially an independent factor so long as it is disaggregated from association with deprivation data when used in this context. Had we used the broader more global Broadband Digital Deprivation Index as the measure, these associations would not have been seen, confounded by strong collinearity with IMD. BII in its own right can be utilised to demonstrate variation by geographical locality. Our own data showing localities that stood out as less well provisioned emphasises the point that any such avoidable digital divide is an addressable infrastructure issue. How such variation arose is unknown to us, perhaps by historical chance events, or other practical infrastructure constraints, or because broadband providers are driven by commercial and fiscal but not social imperatives.[24] Nevertheless, geographical variation of provision can only be addressed if measured.

We demonstrate in the crude data and in regression models that BII was associated with variation with demography and with measurable health outcomes. In binary logistic regression, contrary to expectation, the lower provisioned BII group were less deprived, had a lower non-white ethnicity make-up, and the adjusted association with age showed an impact in younger age groups. The association of poorer broadband provision and the health outcomes of both comorbidity and non-elective urgent care has not been previously described at a population level. There arise a number of considerations: while the associations were highly statistically significant, the size of the effect was very small with the independent variables describing <5% of the variance of BII. We are thus simply stating that they can exist. We believe our local findings are unlikely to be definitive and will vary from region to region, the point being that, unless measured, accountable organisations cannot be assured of equitable provision as a platform for equitable access other than perhaps by geography. Regarding geography, published comparisons are generally made between large population blocks at regional or national level,[16 20 26] whereas we have considered broadband provision within a single local healthcare economy drilling down to the LLSOAs[20] and determined that focus at that level ought to be a consideration for local municipal and health authorities.

The distinction between provision and uptake also requires emphasis, perhaps crudely summarised as the distinction between public provision and individual access. The latest UK government and other independent analysis shows rapidly increasing internet usage[16 20 26] with less than 10% of the population being non or infrequent users, although poor usage remains associated with lower income, lesser educational attainment, increasing age, to a much lesser extent ethnicity and gender as well as geographical factors including the rural urban divide. At an individual level, the skill set required for internet usage and the nature of that use is increasingly understood,[26] noting that internet use for health remains relatively low. Regarding the skill set required, 8% of the UK population have no basic level skills and in 21% they are limited.[27] Generally, there is evidence that broadband and internet usage are associated with a variety of benefits among those who are digitally included.[27 28] The concept of the digital divide and digital exclusion arises out of a concern for the capability among individuals and communities to benefit from digital innovations. In healthcare, specific measures have been developed to assess digital literacy including e-Heals[29] and applied in differing digital health interventions. From that has arisen an understanding of the barriers to engagement with such digital health interventions,[30] how and whether health behaviour can be modified[31] and, importantly, that digital health interventions, of themselves, can lead to inequality.[32]

Publicly accessible digital facilities and personal smartphones may be solutions to inequitable home broadband provision, although they have limitations.[20] Broadband access within an individual's home, rather than a community space, is thought important for increasing digital engagement and associated with higher satisfaction, a wider freedom of use and more complex activities including those related to healthcare.[28 33 34] However, bridging the gap from infrastructure to broadband access and internet use, end point access, previously often described as 'last mile access', is likely determined by uptake. As broadband infrastructure provision increasingly becomes a politically recognised social determinant of health and other outcomes,[4 35–38] with reports describing broadband infrastructure as a 'super social determinant of health',[23 39] it perhaps will come to be recognised as a basic social right, especially if there is an overlap between broadband provision and social inequality.[1 12 40] If broadband provision is an investment in the health and wealth of a population, then digital poverty might require greater recognition, for which a direct analogy exits for the provision of energy utilities, fuel poverty and fuel payments.[41]

Caveats, strengths and weaknesses

We recognise that the BII is a geographical parameter and does not tell us about individual digital exclusion, since we do not have such assessments, just as the use of IMD is taken in lieu of individual detailed socioeconomic data.

Our findings are pertinent to our local health economy and may well differ from similarly sized unitary health and social care geopolitical areas.

This study is a cross-sectional time point view in a rapidly changing digital environment.

As a further caveat, we emphasise that only a prospective follow-up study can determine whether broadband provision is able to modify health determinants and outcomes, which surely must be the intent of all digital health initiatives.

With those caveats and weaknesses, we believe this to be the first description of the association between measurable broadband provision and health data at a population level, and we are the first to demonstrate a statistically significant link with certain crucial health outcomes—comorbidity and urgent care.

Our study methodology is generalisable and based on a high quality and complete dataset curated for the local population. This enables assessment at the local level, taking into account local variations and moving away from large scale interregional or national level comparisons.

CONCLUSION

The provision of broadband is but one component of the digital infrastructure capacity and capability required for an individual to access and reap the potential benefits of the digitalisation of health and social care. We describe a methodology to measure such provision and demonstrate that its variation can be determined at a very local level within unitary and health and social care economies. Such differences may be associated with an unintended variation in a populations' demography and with important health imperatives. Such associations cannot be assumed, but are best measured,

Implications for clinicians and policy makers

Local authorities may wish to consider and extend our described methodology to ensure equitable provision of broadband infrastructure.

Individual care providing services and their staff must be aware of the potential constraints faced by their clients and patients as digital interventions are developed, as well as their own limitations.[13 42]

Future research

As is the intent of the WODEN group, hopefully, our work will promote future research in this field to address the many aspects needed to ensure equity in health and care delivery, and the demonstrable avoidance of imparting disequity, as we so rapidly move into the digital paradigm

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval As the data were accrued and analysed to determine the service imperative to be aware of digital exclusion as a potential factor in delivering equitable social and healthcare, and as no selection, or randomisation or intervention occurred, research ethical approval was not deemed necessary, and this was confirmed within local governance processes.

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