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Estimating future dental services' demand and supply: a model for Northern Germany

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Abstract – *Objectives:* To plan dental services, a spatial estimation of future demands and supply is required. We aimed at estimating demand and supply in 2030 in Northern Germany based on the expected local socio-demography and oral-health-related morbidity, and the predicted number of dentists and their working time. *Methods:* All analyses were performed on zip-code level. Register data were used to determine the number of retiring dentists and to construct regression models for estimating the number of dentists moving into each zip-code area until 2030. Demand was modelled using projected demography and morbidities. Demand-supply ratios were evaluated and spatial analyses applied. Sensitivity analyses were employed to assess robustness of our findings. *Results:* Compared with 2011, the population decreased (−7% to −11%) and aged (from mean 46 to 51 years) until 2030. Oral-health-related morbidity changed, leading to more periodontal and fewer prosthetic treatments needs, with the overall demand decreasing in all scenarios (−25% to −33%). In contrast, the overall number of dentists did only limitedly change, resulting in moderate decrease in the supplied service quantities (max. −22%). Thus, the demand–supply ratio increased in all but the worst case scenario, but was unequally distributed between spatial units, with several areas being over- and some being under- or none-serviced in 2030. *Conclusions:* Within the limitations of the underlying data and the required assumptions, this study expects an increasingly polarized ratio of dental services demand and supply in Northern Germany. Our estimation allows to assess the impact of different influence factors on demand or supply and to specifically identify potential challenges for workforce planning and regulation in different spatial units.

Key words: access; dental services research; epidemiology; public health policy

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Access to a specific healthcare service is one dimension of quality of care (1), which impacts on the utilization of this service (2), and can be measured by assessing the theoretical demand for a service and the truly supplied quantity and quality of this service. Data on the association between access to dental services and health outcomes are sparse and contradictory, with some studies not finding any relationship between both variables (3, 4), while others confirm such association (5–7). The contradiction might be caused by different methodologies used and different definitions of access being in place: most studies looked at the average ratio between the quantitative demand for services and the available or supplied services (8), while it is likely that access differs between spatial units. There are only few studies using appropriate methods for evaluating spatially specific access in dentistry, possible reasons for this being that the required methods (involving geographic information systems) are not widely established in dentistry, and that no generally accepted definition of

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a sufficient access is available (9). Oftentimes, the number of dentists per population is calculated to assess access. However, this construct might be flawed. Instead, demand might better be deducted from needs resulting from oral-health-related morbidity and their resulting transformation into demands, with both needs and their transformation into demand being affected by the socio-demography of the analysed population. Similarly, supply will be not only affected by the number of dentists providing services, but also their working patterns, i.e. their weekly clinical working time.

For assessing the spatially specific ratio between demand and supply, available socio-demographic and morbidity data could be translated into qualitative and quantitative demand, while the number of dentists could be transformed into a similarly scaled supply variable. For Germany, a model for estimating such area-specific demand–supply ratios was established and employed to assess changes in the demand–supply ratio in one federal German state between 2001 and 2011 (10). This study found no generalized under-supply with dental services, but an increasingly unequal spatial distribution, which is in conflict with the aim of dental workforce planning for securing a 'widespread, adequate and accessible supply' for dental services (8, 11). In conclusion, dental workforce planning in Germany (and most likely elsewhere) might be challenged twice: On the one hand, the workforce is rapidly ageing and more female, with generally reduced working hours and an increasing spatial concentration of the workforce in urban, not rural areas (11, 12). On the other hand, an ageing, but also shrinking population with significantly altered morbidity and demand patterns makes workforce planning less predictable, especially when considering that both ageing and shrinking are also spatially specific phenomena.

There is the need to estimate both the future demand for and, if uncontrolled, the future supply with dental services. A continuous or accelerated increase in the spatially unfair relation of demand and supply could perpetuate oral-health inequalities (13–16). The present study aimed at establishing a model to estimate supply and demand for dental services in 2030 via small area-based geographic analyses. Analyses were performed for a Northern German federal state, Mecklenburg-Vorpommern, which has been evaluated using similar methods before and has a highly dynamic socio-demography as well as a great urban-rural polarization.

Methods

Study design

This study sought to estimate the supply with and demand for dental services in 2030 in different spatial units in Mecklenburg-Vorpommern. Supply in each spatial unit was estimated by assessing expected losses of dental workforce, and by estimating the future inflow of dentists into each spatial unit via regressing past inflow on various predictor variables. Demand was calculated by linking the projected local population and its morbidities with theoretical treatment needs and associated treatment times, and transforming these needs into spatially specific demands. As various assumptions were required, three scenarios were used to check the robustness of our findings.

Setting

The federal state of Mecklenburg-Vorpommern is one of the least densely populated areas of Germany, with 1.6 million inhabitants (2014) living on 23 211.05 km^2 (69/km^2). The state has six districts and two district-like larger cities (Schwerin, the capital with 91 000 inhabitants, and Rostock, situated at the Baltic sea, with 203 000 inhabitants). The six districts are relatively large administrative units (between 2118 and 5470 km^2, between 155 000 and 262 000 inhabitants), with mostly rural areas and only few mid-sized cities (the third biggest city of the state has 63 000 inhabitants). The next smaller administrative units are municipalities (755 in Mecklenburg-Vorpommern). This study used zip-code areas (ZCAs) as spatial units, as dentist data were only available on this level. There are 176 ZCAs in Mecklenburg-Vorpommern, which overlap between municipalities, while districts contained up to 34 ZCAs.

In Mecklenburg-Vorpommern, the vast majority (>95%) of the population is insured via the statutory (public) insurance, while less than 5% are members of a private insurance company. Thus, most dental treatments are provided under the tenets of the statutory insurance, with dentists having a licence for providing 'public' treatments. Remuneration is performed on a fee-per-item base, with most but not all treatments being fully reimbursed by the statutory insurance (prosthetic dentistry is only partially subsidized, while elective treatments are not at all covered). Dentists with a public licence have the option to provide any additional services and to treat privately insured patients.

Supply estimation

For estimating the regional supply with dental services, a previously validated model (10) was employed. Briefly, data of the longitudinal dental workforce register of the Dental Association of Mecklenburg-Vorpommern from 2001 until 2011 were extracted. The number of dentists per ZCA ranged between 0 and 185, with a mean of 7 dentists per ZCA in 2011. The loss and gain of clinically active dentists in different ZCAs was calculated as follows. Future losses were predicted based on dentists' year of birth, assuming two retirement ages (65 and 67 years based on the current retirement age in the German social pension scheme), with separate analyses for male and female dentists (Fig. 1a). Note that dentists are not bound to these retirement ages, as they do not contribute to the social, but a professional private pension scheme. To predict future gains, we first performed ordinary least-square regression, using spatially specific socio-demographic variables and dentist losses between 2001 and 2011 as independent variables, and the spatial gain of dentists in that decade as dependent variable (Table 1). Socio-demographic predictors were available on district level only and thus distributed between ZCAs prior to the analysis. Variables were first entered simultaneously, and variables with a variable inflation factor above five successively removed to reduce multi-collinearity. Only variables which significantly contributed to the model ($P < 0.1$) were included into a second model. Geographically weighted regression (GWR) was then applied using these remaining variables. GWR yielded regression coefficients and an intercept for each spatial unit, which were then used to estimate potential future dentist gains from 2011 to 2030 (Table 1).

Such prognosis focuses on the distribution of inflowing dentists between ZCAs. It does not consider changes in the total number of inflowing dentists per year. We checked this inflow via

a

	Dentists stock 2011	Dentists loss (retirement age 65)	Dentists loss (retirement age 67)
Male	525	379	351
Female	787	606	559
Total	1312	985	910

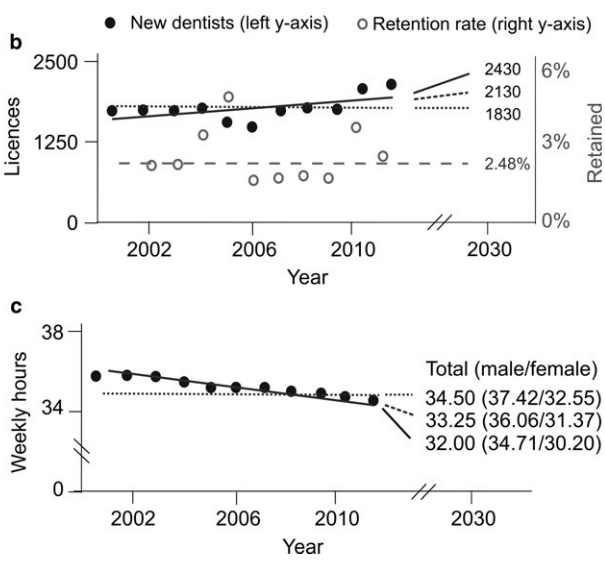

Fig. 1. Estimation of supply with dental services in 2030. (a) Assuming different retirement ages (65 or 67), the baseline stock of dentists (2011) was assumed to decrease. All calculations were performed separately for male and female dentists. (b) The number of newly licensed dentists in Germany (left *y*-axis, black circles) was estimated based on data from 2001 to 2011. Three scenarios were applied (worst case, constant number, best case: continuous linear increase, moderate case: in-between). The retention rate of newly licensed dentist in the federal state of Mecklenburg-Vorpommern (right *y*-axis, rings) was assumed to remain constant at 2.48%. (c) Based on reported weekly working hours, effective working hours for male and female dentists were modelled in three scenarios (worst case: continuously linear decline; best case: constant; moderate: in-between). Data from (a) and (b) were used to estimate the net gain of dentists, and working times (c) used to assign the annual supply (Table 1). All calculations were performed on zip-code level, state-wide level data were only used for summarily display.

Table 1. Prediction of local gain of dentists

	2011 Mean (range)	OLS model 1 $R^2 = 0.99$; $P < 0.001$ Mean coefficient (95% CI)	OLS model 2 $R^2 = 0.99$; $P < 0.001$ Mean coefficient (95% CI)	GWR Model $R^2 = 0.99$ Mean coefficient (95% CI)
Population density (population/km²)	116 (16–1481)	0.00 (0.00/0.00); $P = 0.037$	0.00 (0.00/0.00); $P = 0.013$	−0.06 (−12.0/0.00); $P < 0.001$
Annual household income (Euro)	16 373 (15 167–17 457)	0.00 (−0.01/0.01); $P = 0.406$	–	–
Land price (Euro/m²)	44 (31–100)	0.00 (−0.01/0.00); $P = 0.745$	–	–
Proportion in work (%)	47 (39–54)	0.00 (−0.01/0.01); $P = 0.919$	–	–
Proportion with higher education (%)	17 (14–25)	0.00 (0.00/0.00); $P = 0.102$	–	–
Population per dentist (median, 25th/75th percentiles)	1451 (1093/2176)	0.00 (0.00/0.00); $P = 0.968$	–	–
Dentists loss per year 2001–2011 (median, 25th/75th percentiles)	0.4 (0.0–11.5)	0.90 (0.88/0.92); $P < 0.001$	0.90 (0.88/0.92); $P < 0.001$	0.81 (0.78/0.83); $P < 0.001$

Modelling was first performed using ordinary least-square regression (OLS). Only variables which significantly contributed to this model (OLS model 1) were used to construct OLS model 2 and, subsequently, a geographically weighted regression (GWR) model. Model fit (adjusted R^2 and level of statistical significance) was near perfect for all models. For GWR, the number of lost dentists per year had the greatest predictive value, with a mean of 0.81 dentists gained per one lost dentist. Data obtained via GWR were used to estimate the annual gain per year in each ZCA until 2030 (Fig. 1).

estimating the number of newly licensed dentists in Germany between 2001 and 2011, and calculating how many of these moved or stayed in Mecklenburg-Vorpommern (retention rate). To do so, data provided by the state dental association were used (17). While the retention rate had not significantly changed between 2001 and 2011, the number of newly licensed dentists per year increased (Fig. 1b). Thus, three models were employed – one assuming a constant number of annual licenses until 2030, one assuming a linearly increasing number, and one with a half-linearly increase in the number of newly licensed dentists until 2030. Annual gains in each spatial unit, as predicted via GWR, were adjusted accordingly. For all analyses, the proportion of female to male new dentists was assumed to be 3:2, as this number remained constant over the last decade (17).

Clinical working time of dentists in 2030 was estimated based on repeated cross-sectional working time reports (18). Three scenarios of working times were applied: working time remaining constantly, increasing constantly, or increasing only moderately until 2030 (Fig. 1c). Different weekly working times were assumed for male and female dentists (8). To calculate the annual potential supply, 43 working weeks per year were assumed (8).

Demand estimation

Demand for dental services in 2030 was estimated using an established model. First, the population in each ZCA was predicted using two data from two prognoses (19, 20), which were used in different scenarios (Fig. 2a). Prognosis data were available on district level only, relative changes between 2011 and 2030 in each district were used to estimate population changes in different ZCAs. Second, oral morbidity (number of decayed, missing, filled teeth, proportion of the population with periodontal screening and recording index [PSR] ≥ 3) in different age groups was predicted based on extrapolation of repeated cross-sectional data (21, 22). Third, five dental treatment complexes were defined (operative/surgical dentistry, prosthetics, periodontology, orthodontics, prophylaxis), and used to link past morbidity to provided treatment times via insurance claims data (18). Thus, factors for transforming morbidity into demand-time were estimated. The following assumptions were made: decayed and filled teeth were assumed to generate restorative and surgical needs, missing teeth to generate prosthetic needs, cases with PSR ≥ 3 to generate periodontal treatment needs according to their number of remaining teeth, and individuals aged 15 years or younger to generate orthodontic and prophylactic treatment needs. In the

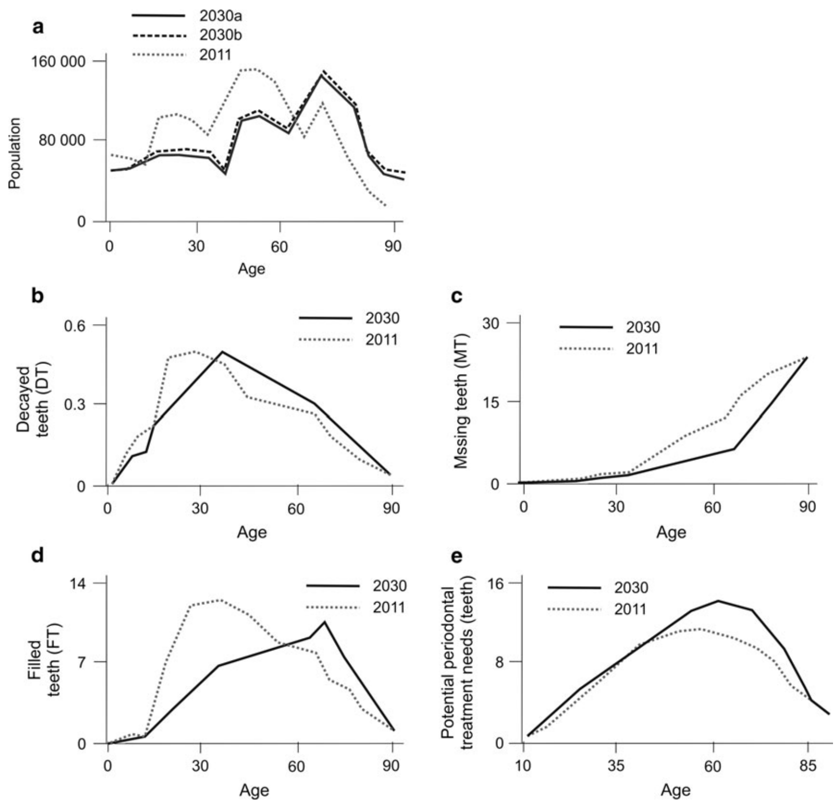

Fig. 2. Demography and oral-health-related morbidity in 2011 and 2030. (a) The state-wide population will significantly age between 2011 and 2030; two different prediction models were employed for subsequent calculations (2030a, 2030b). Predicted morbidities were then linked to required treatment times. Reported number of decayed teeth (DT, b), missing teeth (MT, c), filled teeth (FT, d) and periodontally affected teeth (e) in each age group.

established model, demand was assumed to be lower in populations aged 70 years or older (23). The impact of this assumption was checked by increasing the cut-off to 75 years, as future elderly might be healthier, have more teeth, and would consume dental services until higher ages.

Scenarios

Three scenarios were constructed, combining different assumptions. Each scenario was defined by the predicted population in 2030, the age cut-off at which demand was assumed to decrease, the different annual gains of dentists depending on the numbers of newly licensed dentists, and gender-specific working hours.

By combining the less positive population scenario, the earliest age at which demand was assumed to decrease, the highest annual numbers of newly licensed dentists and the longest weekly working hours, a best case scenario (highest supply and lowest demand) was constructed. Vice versa, a worst case and a moderate scenario were constructed, each combining different assumptions with each other.

Analyses

The distribution of socio-demographic variables and the supply and demand for dental services was analysed statistically and spatially. To estimate the spatial distribution of the ratio between demand and supply (<100% under-serviced, >100% over-serviced), the Gini coefficient was calculated. The Gini coefficient is commonly used to assess income inequality. Values of 0 indicate perfectly equal distribution of the demand–supply ratio, values of 100 indicate perfect inequality (24, 25). Spatial analysis included mapping of demand-supply ratios and analysis of clustering. Spatial autocorrelation between surrounding ZCAs was assessed via global Moran's I (26). Local clustering was evaluated via Local Indicators of Spatial Autocorrelation analysis. Association between socio-demographic variables and the population per dentist density in 2030 was evaluated via bivariate analyses using Spearman's correlation coefficient and linear regression analysis, and via ordinary least-square regression and GWR as described. Statistical and spatial analyses were performed using

SPSS 20 (IBM, Armonk, NY, USA) and ArcGis 10.2 (Esri, Redlands, CA, USA).

Results

Compared with 2011, the state-wide population decreased (−7% to −11%) and aged significantly (from mean 46 to 51 years) until 2030, with a slightly higher number of (slightly younger) inhabitants in the worst case compared with alternative scenarios. Based on these population prognoses, demand for different dental services was calculated (Table 2). Total demand decreased significantly in all scenarios (−25% to −33%), with greatest decrease for prosthetic services, while the demand for periodontal services increased. The overall number of dentists did only limitedly decrease in the moderate and worst case scenario (−22%), and even increased in the best case scenario. The same was found for the overall annual working time (Table 2). Subsequently, the density of population per dentist did not dramatically change in the moderate scenario, and decreased and increased in the best and worst case scenario respectively.

The median ratio of demand to supply was nearly perfect in 2011 (98%). Due to the decreased demand per capita (i.e. decreased morbidity), this ratio increased in 2030 in the moderate and, more so, in the best case scenario. Only in the worst case scenario did this ratio decrease. However, the distribution of this ratio in different spatial units was increasingly unequal in 2030 compared to 2011 regardless of the scenario as indicated by percentiles and Gini coefficients (Table 2). Spatial analysis confirmed this unequal distribution (Fig. 3), with large areas being over-serviced (ratio >100%), but some areas being under- or not at all serviced in 2030. Global spatial autocorrelation was limited in all scenarios (Moran's I was 0.15 [Z = 1.43, P = 0.15] in the moderate, 0.15 [Z = 1.38, P = 0.17] in the best, and 0.17 [Z = 1.63, P = 0.10] in the worst case scenario respectively). In only few areas, a clustering of ZCAs with high ratios with each other (high-high) or with ZCAs with low ratios (high-low) was found (Fig. 3).

Using correlation and regression analyses, we evaluated if socio-demographic characteristics predicted the population-to-dentist ratio in 2030 in different ZCAs (Table 3). While bivariate analyses indicated that with increasing population density, the population-to-dentists ratio increased as well, this was not confirmed by multivariate analysis. Using GWR, we found a positive correlation in some, but not all areas (Fig. 4). Overall, the constructed model had moderate fit (R^2 = 0.42).

Table 2. Demand for and supply with dental services in 2011 and 2030 in each ZCA

		2030		
	2011 (10)	Moderate	Best	Worst
Population	1 634 734	1 451 887	1 451 887	1 525 038
Mean age	45.8	51.2	51.2	50.9
Reduced demand at	≥70 years	≥70 years	≥70 years	≥75 years
Demand (% of total)				
Conservative operative	731 981 (48%)	482 087 (48%)	482 087 (48%)	538 296 (47%)
Prosthetics	496 508 (33%)	258 137 (26%)	258 137 (26%)	297 666 (26%)
Periodontology	97 787 (6%)	127 418 (13%)	127 418 (13%)	147 650 (13%)
Orthodontics	139 252 (9%)	102 980 (10%)	102 980 (10%)	110 165 (10%)
Prophylaxis	54 071 (4%)	39 986 (4%)	39 986 (4%)	42 776 (4%)
Total	1 519 598 (100%)	1 010 608 (100%)	1 010 608 (100%)	1 136 553 (100%)
Dentists (male/female)	1312 (525/787)	1222 (504/718)	1346 (553/792)	1099 (455/644)
Weekly working hours	34.50	33.25	34.50	32.00
Total annual hours	1 945 256	1 750 410	1 999 378	1 514 715
Population per dentist (median, 25th/75th percentiles)	1451 (1093/2176)	1425 (1047/2388)	1302 (962/2174)	1688 (1213/2841)
Ratio demand/supply in % (median, 25th/75th percentiles)	98% (59%/143%)	120% (60%/187%)	137% (68%/211%)	90% (48%/140%)
Gini coefficient	44.40	49.06	49.13	48.39

Number of ZCAs was 176. For 2030, three different scenarios were modelled, each based on a combination of assumed input estimate. The ratio of demand per supply indicates potential over- or under-servicing. The Gini coefficient indicates the equality of the distribution of this ratio between spatial units (ZCA).

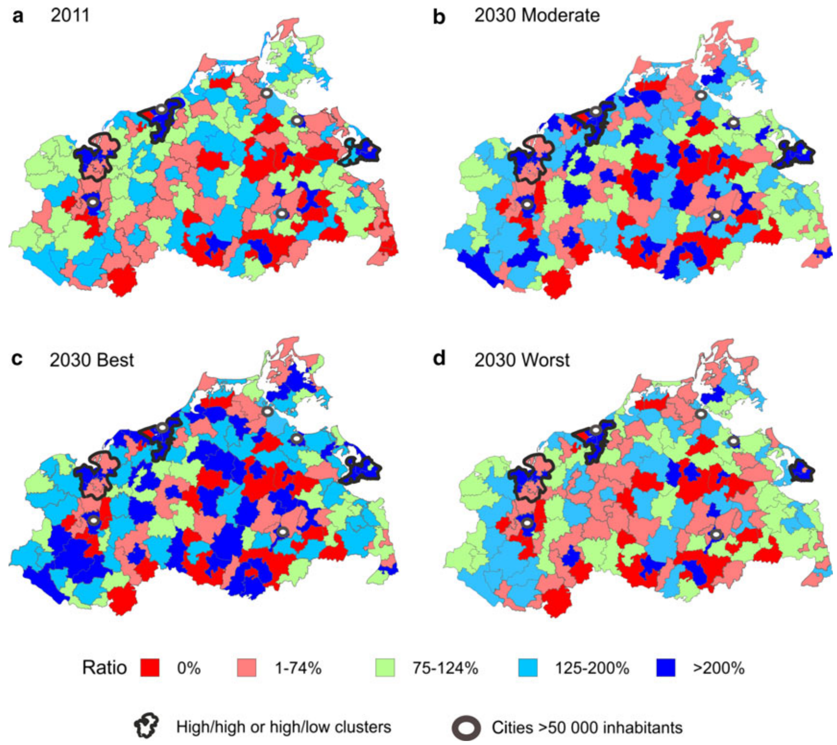

Fig. 3. Ratio of demand and supply in 2011 (a) and 2030 (b–d) in different spatial units (zip-code areas). Under-serviced areas (supply of 0% or between >0% and 74% of the demand) are indicated by red and pink, respectively, while over-serviced areas are indicated by light and dark blue (supply 125–200%, or above 200% of the demand). Areas with matching demand and supply (ratios of 75–124%) are shown in green. The five biggest cities (>50 000 inhabitants) are indicated by black rings. Areas with spatial clustering (high-high, i.e. blue–blue, and low-high, i.e. blue–red,) are highlighted by an accented border. Different scenarios were analysed based on a combination of different assumptions (b–d).

Table 3. Bi- and multivariate correlation analyses between socio-demographic variables and the population-to-dentist ratio

	Values	Bivariate		Multivariate	
		Spearman	GWR	OLS R^2 = 0.07 Mean coefficient (95% CI)	GWR R^2 = 0.42 Mean coefficient (95% CI)
	Mean (range)	R^2	R^2		
Density 2030 (pop./km²)	119 (18–1535)	0.42	0.42	–	0.0 (−0.1/0.1)
Annual income 2011 (Euro)	13 328 (12 795–14 282)	−0.08	0.03	–	–
Land price 2011 (Euro/m²)	48 (38–84)	0.06	0.02	–	–
Working population 2011 (%)	42 (39–44)	−0.25	0.04	−10.3 (−18.0/−2.5)	–
Higher education 2011 (%)	12 (10–12)	0.02	0.01	8.4 (0.9/16.0)	–

Only one socio-demographic variable was available for 2030 (population density); other predictors were only available for 2011. Spearman's coefficient and geographically weighted regression (GWR) were first used to evaluate a possible bivariate association between each socio-demographic variable and the population per dentist in each ZCA (number of ZCAs was 176). Bivariate analyses found only limited correlation (R^2) for all variables except population density. For multivariate analysis, ordinary least-square regression was used firstly, with only two variables being retained ($P < 0.1$), and very low overall fit of the model ($R^2 = 0.07$). For GWR, the association between population density varied in different spatial units, with certain areas showing a negative, and others showing a positive correlation (see Fig. 4 for more details).

Discussion

Estimating future demand for and supply with dental services is relevant and increasingly complex given a population with spatially unequally ageing, shrinking, morbidities and service utilization patterns. This study applied a validated model

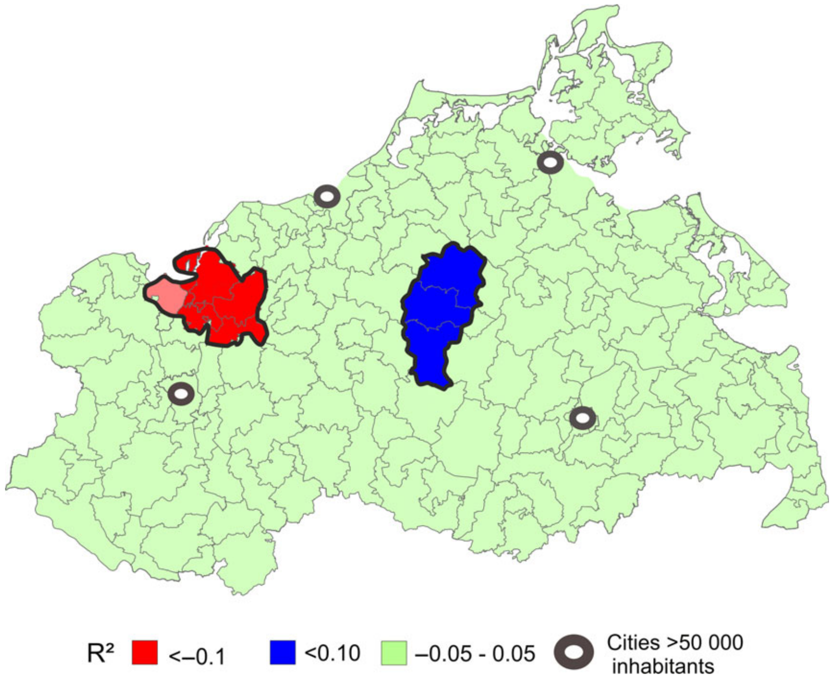

Fig. 4. Prediction of population-to-dentist ratios according to the population density. Geographically weighted regression was used to estimate spatially specific coefficients. In few ZCAs, a negative correlation was found (red or pink), while in others, the association was positive (blue). In most areas, correlation coefficients were low (between −0.05 and 0.05, green colour).

to estimate the spatial specific demand based on age-adjusted morbidity data. The future supply in different spatial units was estimated using dentist cohort data, accounting for potential changes in the composition and working patterns of the future workforce. We then compared demand and supply, with spatial analyses being able to identify areas at risk of future under- and over-servicing.

In all assessed scenarios, a large regional variety between demand and supply was found, with many areas being potentially over-serviced, but few (mostly rural) areas being without any local dental service at all in 2030. While a possible compensation of under- with over-servicing and vice versa from neighbouring spatial areas has been reported (27), our analyses, for example using Moran's I, did not confirm such compensation. Our results further highlight the limited value of average (national or state-wide) estimates, which do not reflect the local demand and supply. If assessed on average, none of the scenarios found under-servicing in 2030, which has been defined as a ratio of dentists per population of 1:5000–1:4000 depending on need (9), but rather significant over-servicing.

In our model, the number of future dentists moving into an area was estimated based on the number of dentists who stopped being active in this area. This assumption, admittedly, introduces great uncertainty, as the decision of where to settle will – in reality – incorporate far more factors, which are likely not to be static over the next 15 years. However, given the perfect fit of the model for the decade between 2001 and 2011, we found the used model suitable for attempting a prediction; moreover, we used sensitivity analyses to assess the robustness of our findings. Nevertheless, caution is required when interpreting our results, as especially for small ZCAs (e.g. those with only one or two dentists present in 2011), the uncertainty resulting from our assumptions might have great impact on the estimated supply in 2030.

The inflow of dentists further depended on the national number of newly educated dentists in Germany, and their retention in Mecklenburg-Vorpommern. Both numbers are not known, and no regulation is in place for controlling the number of future licenses. Again, sensitivity analyses were used to assess the impact of the resulting uncertainty. The average ratio of demand and supply in 2030 matched only in our worst case scenario. In both other scenarios, average over-servicing was predicted. Similarly, in all scenarios, the distribution of supply and demand was highly polarized. Despite their uncertainty, these findings highlight the relevance of dental workforce planning, especially as both German dental education and services are financed by the public (2).

A variety of options have been suggested for controlling the distribution of medical workforce, and while most of them have not been evaluated in dentistry yet, they should be briefly discussed here. One measure which is both politically available and effective (and has been used in German dentistry in the past) is demand-based licensing. It is easy to implement and enforce, not costly, and especially useful for tackling over-supply (28). Such quota could be established by the federal state's dental association, which has been granted autonomy for securing an adequate service supply. In contrast, changing the remuneration system from fee-per-item to capitation might be effective to increase spatial dispersion of dentists (28), but could only be implemented nationally, involving a complete overhaul of German dental care, and is thus highly unlikely. Given that Mecklenburg-Vorpommern has two universities which educate future dentists, dental training might be used to guide dentists towards rural, possibly under-serviced areas, for example, via practice-based education in such rural areas, or recruitment of students with interest and affinity for working in less urban regions. Dentists might be willing to move to under-serviced areas if budget constraints (which are in place in Germany) were relaxed or adjusted demand-specifically (at present, these are uniform across the federal state). Financial bonus could be paid for moving or staying in rural ZCAs (as is currently done for general practitioners in many areas in Germany). While the latter measures are all theoretically available, there is evidence that they might lack effectiveness while generating significant costs (28). It remains unclear if future younger dentists might generally be more mobile and willing to move to rural areas, as data for physicians indicate (29), or trending more towards urban areas (30).

The used model for estimating spatial specific demand first calculated age- and morbidity-adjusted needs and then transformed these into demand, taking into account age-specific consumption of services. This model has been validated before and found suitable to estimate both the average demand and the service composition (i.e. the proportion of different services per total demand). Based on our model, a general decline in dental treatment needs might be expected given the shrinking population. Moreover, a shift from prosthetic to periodontal needs is likely, accounting for the higher number of retained teeth even in older age groups. In relative terms, prosthetic treatment needs will account not for one third, but only one quarter of overall needs, while periodontal treatment needs will expand in relative and absolute terms (being the only dental field with absolute growth). The proportion of conservative, orthodontic and prophylactic treatments is not expected to greatly change between 2011 and 2030. It should be noted that such predictions are based on two main factors; demographics and expected morbidity, both of which cannot be fully predicted, but have been shown to change along certain trajectories in the past (19–21). Nevertheless, it remains unclear if there will truly be a shift in demands, as both patient- and supply-side factors might hamper the full translation of needs into demands (18). If the expected relative changes in the composition of dental services demand were to hold true in the next years, our estimates might be used to guide future dental education and could inspire different service patterns: in many countries, periodontal treatments are performed not only by dentists, but dental healthcare professionals like hygienists or therapists. This is not the case in Germany at present, as periodontal treatments can only be performed by dentists by law. If these regulations changed, over-servicing with dentists would be even greater than predicted. For other countries, the used model should be adapted to account for such mix of service providers. Similarly, the used model only simulates demand and supply within the public health service. This was done, as data on privately provided services are not publically available in Germany, and was justifiable for the evaluated federal state given the low number of privately insured patients, and the low proportion of nonpublic treatments (31). For other states or countries, this will not apply, and require adaptation.

This study and the underlying model have several limitations. First, the entered socio-demographic variables stemmed from district, not zip-code spatial levels, and were too coarse to predict the ratio of demand and supply sufficiently. Therefore, our model was not based on socio.-demographic variables (except population density). Future studies might strive for incorporating data with more spatial detail to increase the precision and robustness of their findings. Second, the used demand model builds on morbidity data, which was linked to claim data and subsequently transformed into working hours. Claim data might not fully reflect on underlying needs, as provided treatments are possibly affected by other factors (costs, preferences, applicability, acceptability). In addition, provided treatments might change with time based on an evolving evidence-base or changing macro-economic or political conditions. One such factor impacting on demand might have been the quarterly entrance fee for the consumption of therapeutic (not preventive) dental services in Germany between 2004 and 2012. The impact of economic changes might be limited given that in the specific setting, most patients received dental treatments at no or greatly reduced costs. Third, the morbidity in Mecklenburg-Vorpommern might differ from the German average, as reported before (32). However, the estimates of the available state-specific studies are not comprehensive, usually restricted to few age groups, not wholly representative and also not available for smaller spatial units (districts, zip-code areas). Similarly, the assumed transformation of needs into demand will not be uniform: For example, a greater transformation of demand in urban than rural areas could partially compensate for the observed urban over- and rural under-servicing. Claim data on zip-code or district level would be required to test this hypothesis. Last, the provided dentist data were available on zip-code level only, which does not allow estimating distances or assessing means of transport.

In conclusion, the applied model can be used to estimate the future demand and supply for dental services, incorporating the socio-demography of both general population and the local dentists as well as oral-health-related morbidity. Our estimates show a significant polarization of dental services supply and demand in 2030 in Northern Germany. The yielded estimates allow to assess the impact of different influence factors on demand or supply and to specifically identify future challenges in different spatial units. Based on our findings, stakeholders in dental workforce planning can be liaised and advised. Interpretation of any data stemming from our model should be performed with great caution given the uncertainty of the required assumptions and the used data.

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