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Using GIS to analyse dental practice distribution in Indiana, USA

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Objective: Dentistry across the globe faces significant workforce issues with mal-distribution at most levels of analysis being a substantial issue. This study was the first to apply high resolution Geographic Information Systems (GIS) tools to map every private dental practice in the State of Indiana against a backdrop of population demographics. The hypothesis tested in the study is that there is an even density distribution of dental practices across Indiana. **Method:** Adult population data were obtained from the United States Census of Population and divided by census tracts. The physical address for each dental practice in Indiana was collated from a comprehensive web-based search and the two datasets were integrated using GIS tools. **Result:** The whole adult population of Indiana (5 million) was distributed across 1,511 census tracts. Across these tracts a total of 2,096 separate private general dental practices were distributed. There were a total of 679 tracts (45%) without a dental practice while 2.5% of tracts had 8 or more practices**. Conclusion:** The practice to population ratio (1:2,384) for the whole State was not significantly different for those living within 50km (31 miles) or 25km (15 miles) of the seven major city centers, and mean personal income (by residency location) did not appear to significantly influence practice location.

Key words: *dentistry, GIS, population access, Indiana*

Introduction

Dentistry across the globe faces significant workforce issues with mal-distribution at most levels of analysis being a substantial issue (Kruger *et al*., 2012, Saman *et al.,* 2010). Much of the research, planning and policy activities in dental public health has been based on sampled data of dentist, practice and population, and practice to population ratios (Vujicic *et al.,* 2012). These sample-based studies are used extensively by researchers and governments to argue for various public health initiatives to address regional workforce shortages (Valachovic, 2009). With modern tools however, high fidelity data on workforce distribution can now be accessed and analysed. Dental care in the US is largely provided by private dental practices on a user pays basis (Valachovic, 2009). Therefore, accessibility to private dental practices is a key issue in access to dental care (Kruger *et al.,* 2011). In areas of low population density, the viability of private practices is often a disincentive for initiating a practice and therefore, people living in low density regions often suffer from poor access (Kruger, *et al.,* 2011). This study aims to examine the accessibility to practices (i.e. the distribution of practices, and not the number of practitioners relative to the population; this is a subtle but important difference as more than one practitioner may work at a single practice and there are occasions when a practice location may only be used part-time). The State of Indiana has a relatively low population spread over a significant area and therefore access issues in rural areas of the State could be expected. In addition, with dental practices being user-pays based, it would be reasonable to assume (and consistent with other parts of the world) that areas of poverty will see a dearth of practices, whilst more affluent areas would have greater densities of dental practice. Previous work by our group in Australia and New Zealand has shown a linkage between deprivation and a dearth of practices (Kruger *et al.,* 2011; 2012).

This study applied high resolution Geographic Information Systems (GIS) tools in an attempt to locate every private dental practice in the State of Indiana and to map these practices against population (and indicators of socio-economic deprivation). The hypothesis tested in the study is that there is an even density distribution of dental practices across Indiana.

Methods and Materials

All data were collected from open sources and therefore no ethics approval was required.

Regarding population data, all adult (over 16 years old) population data were obtained from the United States Census of Population (USCP, 2010) and divided by census tracts (USCP, 2012a; 2012b). The study was limited to adults for comparative purposes as in many countries dental services for children are influenced by state insurance schemes or direct service models (Dyer *et al.,* 2013). These data are freely available through the web. Tracts were chosen as the geographic regions for this study as the statewide density of practices and population indicated that these divisions would retain the integrity of the data analysis using high fidelity geographic distributions. Census tracts covered all of Indiana. Also collected from the census website was the average household income for each census tract. A nominal split of average income was set at US$20,000 per household per annum to simplify the results presentation; however complete data is presented in the tables.

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For practice location, the physical address for each private dental practice in Indiana was collated from a comprehensive web-based search. These addresses were cross-checked against the Yellow Pages business directory as at August 2012, and a sample against the dental register of Indiana. All addresses were entered into a database and the longitude and latitude of each practice address was obtained using a free access geo-coding website (Google, 2012). A randomly selected sample of 1-2% of all geo-coded practices was tested against personal knowledge to test the integrity of the data (the confirmatory sample was found to be 95% concordant with the data collected from electronic sources). Of all private practices, fewer than 1% could not be geocoded (i.e. address not locatable) and were excluded from the study as were specialist practices. This expanded approach to gaining addresses was used to ensure that people practicing at more than one physical site were included for each site.

All data analysis, including the calculation of practice-to-population ratios, was completed using Excel (v2003). Geographic boundary data for each census tract were integrated with the population data and dental practice addresses using ArcGIS (v.10, ESRI, Redlands CA, US) based on the longitude and latitude of the regions and the addresses. All data for analysis were then extracted from the integrated geographically aligned database.

Results

The whole adult population of Indiana (5 million) was distributed across 1,511 census tracts. Tracts were of different sizes and geographic areas and had populations up to 12,000 (average of approximately 3,320). Across these tracts a total of 2,096 separate private general dental practices were distributed (Figures 1 and 2). The overall practice-to-population ratio was approximately one practice per 2,384 people.

Some 679 tracts (45%) did not contain a dental practice, while 2.5% of tracts had 8 or more practices (Table 1). Between 16 and 18% of practices were either the only practice or one of only two or three practices in the tract, while 19% (n=392) of practices were in tracts with 8 or more practices. Over 2.2 million people (45%) live in census tracts that have no practice and 1.3 million people (26%) live in tracts with a single dental practice (Table 1). The practice to population ratio varies between 3,354 people per practice for single practice tracts, down to 276 people per practice in tracts with 8 or more practices.

Dividing the State into census tracts with a mean individual income of above and below $20,000 reveals that 61% of the population is in the lower bracket (Table 2). However, the proportion of people living in tracts with different numbers of dental practices did not vary greatly between high and low mean incomes. For example, of the 1.27 million people living in tracts with just a single dental practice, 760,000 live in tracts with a mean income under $20,000, while 513,000 live in tracts with a higher mean income. This equates to 25% of all low income earners and 26% of all high income earners, not a significant difference.

For analysis the State's tracts were classified into three zones: tracts with centroids within 25km (15 miles) of the center of any of the seven major cities; those within 50km (31 miles) but not within 25km; and those outside 50km. This reveals a similar pattern of apparent non-significant association between location, and practice to population ratio (even when adjusted for income). Overall for Indiana, the dental practice to population ratio was 1:2,384, within 50km it was 1:2,250, and within 25km it was 1:2,316 (Figure 3). When income was included in the analysis, some variation was noted but the pattern was not consistent (Figure 4). The highest ratio (greatest number of people per dental practice) was in the lowest income bracket (mean individual income below $10,000) where those living within 50km (but outside 25km) was 1:5,500.

Discussion

This study found that the distribution of dental practices across Indiana was not significantly influenced by either population density or income. There was a relatively stable practice to population ratio for those living within 50km or 25km of the seven major city centers and no dramatic change in these ratios from that for the whole State. In addition, adjusting for mean income, there was also limited variation in practice-to-population ratios.

In comparison to previous studies these data differ from much of the international research where practice-to-population ratios diminish dramatically with distance from cities (Kruger *et al.,* 2011). For example, data from Australia finds very significant gradients in dentist density. Similarly, some English data point to similar patterns (McCormick *et al*., 2008), although the effect in England is somewhat diminished, as a strong government regulatory model masks the economic drivers.

Earlier work from Ohio using postal code level data, found dentist density (bearing in mind that this was not practice level, but operator level data) was lower in non-city counties (Horner *et al.,* 2007). They concluded that there was a significant disparity. This is consistent with the various other US studies of dentist to population ratios and distributions.

The contrast in outcomes from the previously reported work, and that of this high fidelity GIS based approach, could be driven by many factors. It is clear that different factors are being measured and arguments about which is more pertinent can be made. Dentist-to-population or practice-to-population ratios are different measures. The latter is more specifically targeted at the question of access, and more likely to be a better index in a shortage environment and for emergency care. A second factor in the differences may be the level of measure as statistical theory explains that the fidelity of a measure influences the outcome. In this case (at high resolution) the data reported may, purely on the basis of mathematical approach, find an outcome that differs significantly from other methodologies. Lastly, it could actually be that there is less of a gradient of dentist to population in Indiana than in other parts of the US.

Importantly, it must be remembered that remoteness and paucity of service is a sociological construct. People's perception of access is a more important driver than

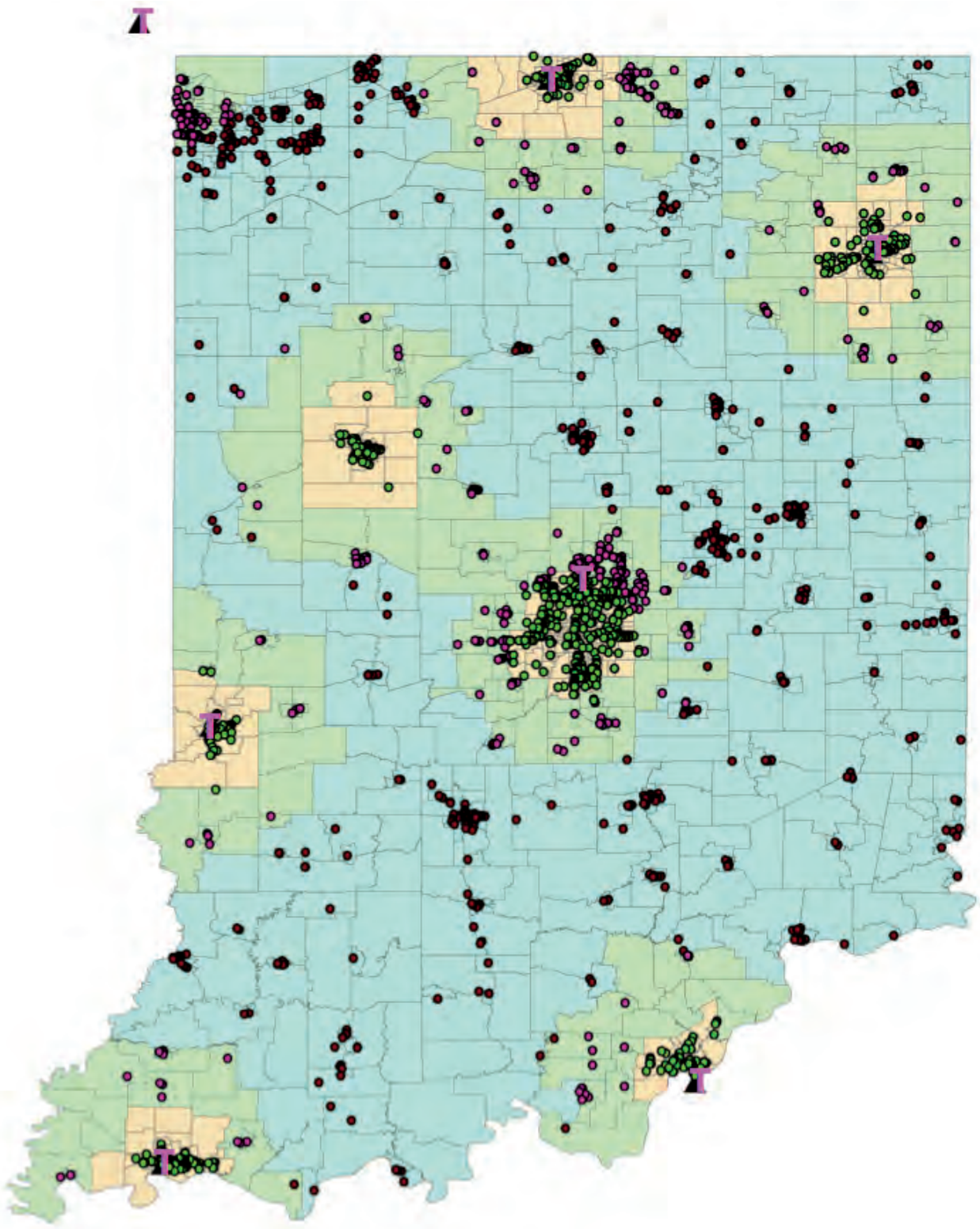

Figure 1. *A map of Indiana census tracts overlaid with dental practices (dots). Tracts are shaded yellow if their centroid is within 25km (15 miles) of the center of one of the seven major cities (black triangles with pink "T" overlay), green for within 50km (31 miles) and blue for the rest. Green dots are practices within the 25km zone while purple are those outside.*

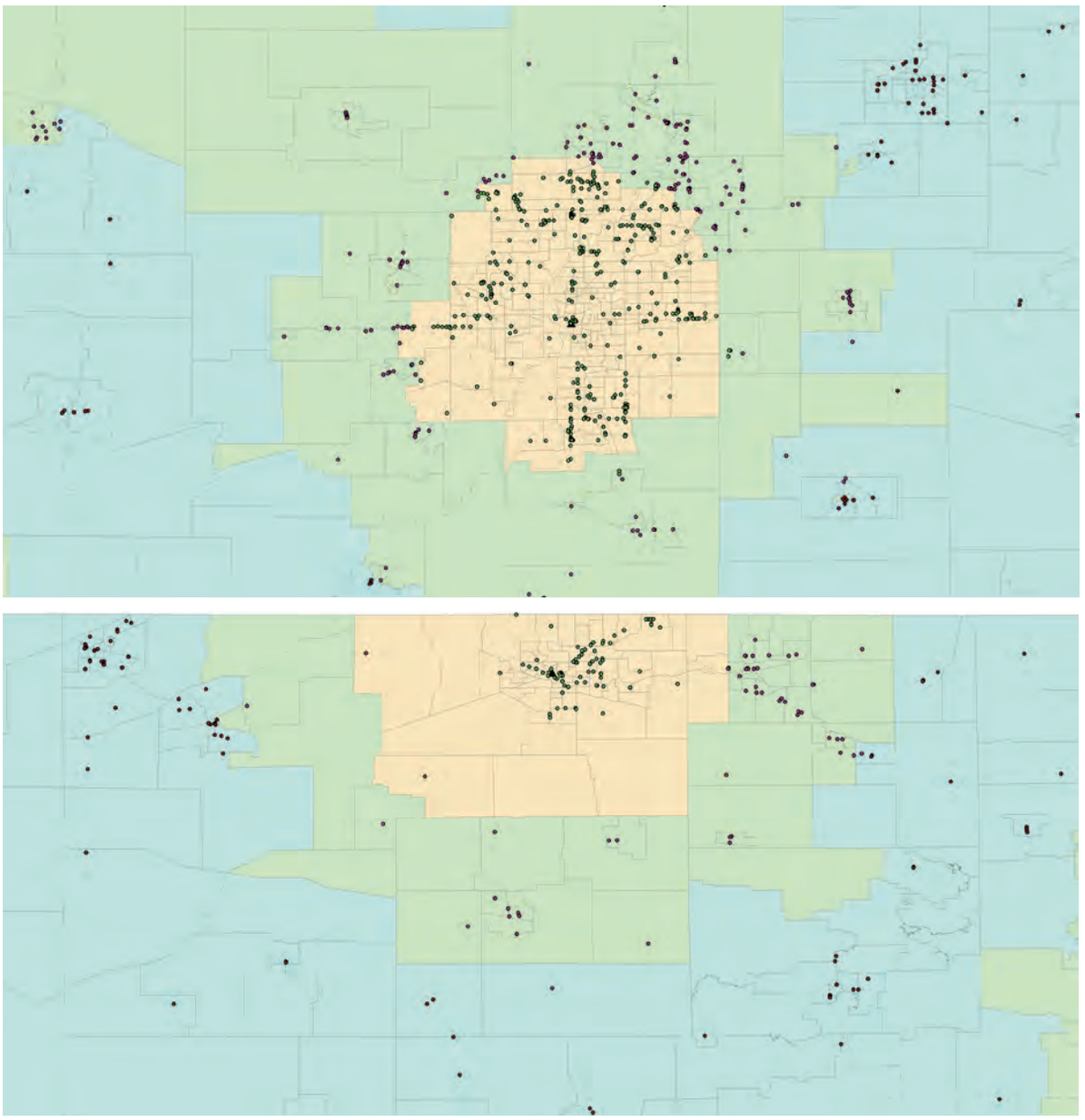

Figure 2. *High resolution maps of Indianapolis (top) and South Bend (bottom) overlaid with dental practices (dots). Tracts are shaded yellow if their centroid is within 25km (15 miles) of the center of the city (black triangles), green is within 50km (31 miles) and blue for the rest. Green dots are practices within the 25km zone while purple are those outside.*

distance. For example, in Australia dental practice-to-population ratios have been previously published using boundaries of 150-200km (93-124 miles) as accessible (Perera *et al*., 2010). The applicability of these distances to smaller places such as Hong Kong is clearly not appropriate. Similarly, the views of accessibility (travel time and distance) to health services for people living in Alaska with will be quite different to those of New York. In addition, it should be considered that population can rapidly shift between places (cities) with the right economic drivers, while practices may not move at the same time. This differential chronology of movement may influence the results. Quantitative measurement of services and population is only one facet of the multi-factorial accessibility rubrics, and sociological factors (such as community expectations) are an important part of the overall story.

Clearly, this study has some data limitations; analysis of physical practice location is not a perfect transition into accessibility as this relies on the level of service provided at each clinic. It may well be that some clinics are "full" and taking no new patients. In addition it may be that care profiles between clinics may differ too. However, within these limitations the use of general practice locations still provide a good level of indication of access. Health service accessibility is complicated by many variables beyond straight geography. Social and ethnicity variables also influence the demand side for care (Kruger *et al*., 2010). Some communities limit the access to services based on custom or historical links that are not purely about time-to-clinic factors. Similarly, weather and transport corridors will influence decisions of access and these are part of future studies.

Table 1. The number of dental practices by census tract and population for Indiana

Count of practices per tract	*Tracts*		*Practices*		*Population*		*Practice to Population ratio*
	n	*%*	*n*	*%*	*n*	*%*	
0	679	44.9	0	0	2,259,694	45.2	
1	380	25.1	380	18.1	1,27,4687	25.5	3354
2	180	11.9	360	17.2	583,346	11.7	1620
3	110	7.3	330	15.7	371,418	7.4	1126
4	48	3.2	192	9.2	157,604	3.2	821
5	34	2.3	170	8.1	103,008	2.1	606
6	22	1.5	132	6.3	66,697	1.3	505
7	20	1.3	140	6.7	72,213	1.4	516
Over 7	38	2.5	392	18.7	108,089	2.2	276
All	1511	100	2096	100	4,996,756	100	

Table 2. The total population of census tracts with mean personal income above and below $20,000 presented by various numbers of dental practices per census tract

Income	*Number of practices per census tract*									*Whole sample*
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Over 7*	
Low income	1,290,989	76,2014	416,872	233,735	97,564	79,042	34,097	39,164	84,377	3,037,854
High income	968,705	512,673	166,474	137,683	60,040	23,966	32,600	33,049	23,712	1,958,902
All	2,259,694	1,274,687	583,346	371,418	157,604	103,008	66,697	72,213	108,089	4,996,756
% low income	57.1%	59.8%	71.5%	62.9%	61.9%	76.7%	51.1%	54.2%	78.1%	60.8%
Low income*	42.5%	25.1%	13.7%	7.7%	3.2%	2.6%	1.1%	1.3%	2.8%	100%
High income*	49.5%	26.2%	8.5%	7.0%	3.1%	1.2%	1.7%	1.7%	1.2%	100%

*Proportion of low and proportion of high income earners according to the number of practices per census tract

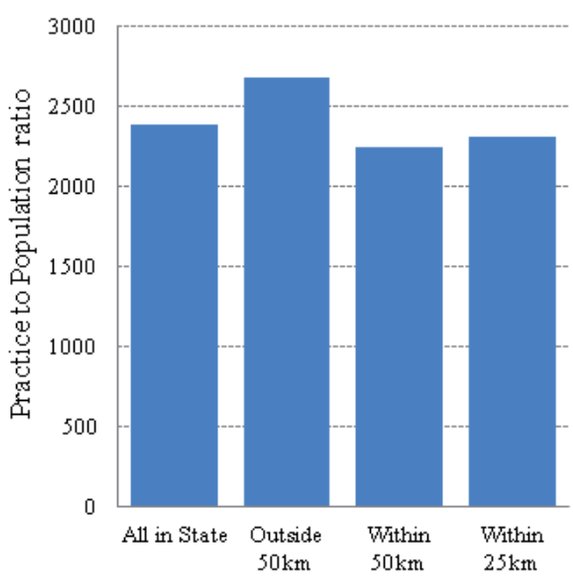

Figure 3. *Dental practice to population ratio for all in the State, within 50km (31 miles) but outside 25km (15 miles) of the seven major cities and within 25km of any of the seven major cities*

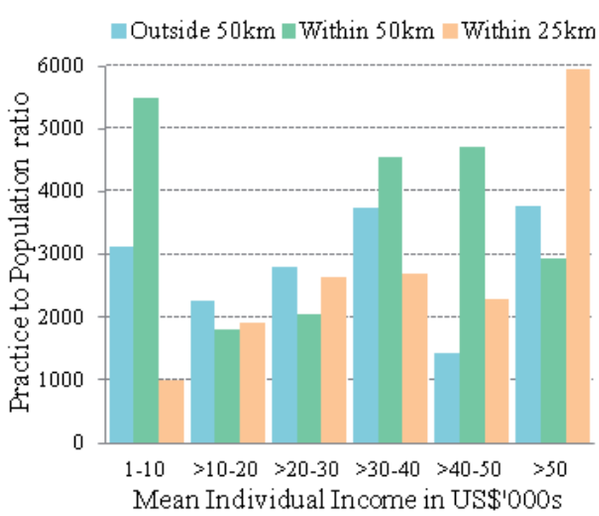

Figure 4. *The practice to population ratio for each income bracket for the three zones; within 25km (15 miles) of any one of the seven major cities, within 50km (31 miles) but outside 25km of one of the seven major cities or outside 50km*

Conclusion

Indiana is a state of approximately 5 million adults distributed across 95,000 square kilometers (59,030 square miles). It is estimated that there were just fewer than 2,100 dental practices distributed across the State. The practice-to-population ratio (1:2,384) for the whole state was not significantly different for those living within 50km or 25km of the 7 major city centers, and mean personal income (by residency location) did not appear to significantly influence practice location. Population density and the socio-economic status of the community do not appear to be linked to dental practice location in Indiana.

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