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Should Measures of Health Care Availability Be Based on the Providers or the Procedures? A Case Study with Implications for Rural Colorectal Cancer Disparities

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Abstract

Purpose: Patients with colorectal cancer (CRC) living in rural areas have lower survival rates than those in urban areas, potentially because of lack of access to quality CRC screening and treatment. The purpose of this study was to compare traditional physician density (ie, colonoscopy provider availability per capita) against a new physician density measure using an example case of colonoscopy volume and quality. The latter is particularly relevant for rural providers, who may have fewer patients and are more frequently non-gastroenterologists.

Methods: We conducted a secondary data analysis of the 2014 Medicare Provider Utilization and Payment Database and the National Cancer Institute State Cancer Profile Database. Volume-weighted physician density scores at the state and county levels were created, accounting for: 1)

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Supporting Information Available Online:Centers for Medicare & Medicaid Services (CMS) 2014 Medicare Provider Utilization and Payment database colonoscopy procedure codes

the physician's annual colonoscopy volume and 2) whether the physician performs 100 procedures per year. We compared volume-weighted vs traditional density, overall and by rurality, and examined their correlation with CRC screening, incidence, and mortality rates.

Findings: The difference between volume-weighted and traditional density scores was particularly large in rural parts of the West and Midwest, and it was most similar in the Northeast. Although weak, correlations with CRC outcomes were stronger for volume-weighted density, and they did not differ by rurality.

Conclusions: Our new method is an improvement over traditional methods because it considers the variation of physician procedure volume, and it has a stronger correlation with population health outcomes. Weighted density scores portray a more realistic picture of physician supply, particularly in rural areas.

Keywords

density; endoscopy; health manpower; health services accessibility; physicians

Physician supply, as a measure of availability of medical care, is associated with various patient outcomes, including stage at disease presentation, preventive services utilization, timely disease treatment, hospitalization rates, and mortality.^{1–9} Estimating the availability of physicians has been a common practice and a topic interest for health services and policy researchers, health system administrators, and insurance companies. This information is useful for intervention planning, resource allocation, disparities research, and workforce research. Physician density is traditionally calculated as the number of physicians in an area divided by the target population. However, this estimate can give an unrealistic picture of the availability of physicians who provide services given the variance in the volume of procedures performed. A simple count of the number of physicians in an area ignores the number of services they collectively provide.

The relationship between physician density and patient outcomes is also subject to variation across demographic subgroups and geographic regions. For example, Plascak and associates found that the relationship between late-stage cancer diagnosis and primary care provider density was strongest among persons with private insurance (vs Medicare, Medicaid, or uninsured).⁶ To determine the availability of specific types of physicians, researchers have relied on physician registries,^{1,10} state licensing board data,¹¹ surveys,¹² Medicaid and Medicare claims,^{13–15} and/or simulation studies.^{16–18} For example, in a study estimating colorectal screening, it was found that primary care physicians performed less than 1 (± 1.1) colonoscopies per month, general surgeons provided a mean of 3 (± 35.0) screening colonoscopies, and gastroenterologists performed a mean of 12 (± 40.2) colonoscopies per month.^{17,19} This equates to gastroenterologists performing the majority of estimated screening colonoscopies (66%), followed by general surgeons (33%), and finally primary care physicians (0.6%). The procedure variance was found to be extremely large compared to the mean, indicating that even within a specialty, procedure volumes may vary dramatically. This suggests that simply counting the number of physicians can distort the measurement of physician density. Therefore, we sought to illustrate these differences in a case study of physicians performing colonoscopy.

Case Study: Colorectal Cancer Screening by Colonoscopy

The United States Multi-Society Task Force on Colorectal Cancer (CRC) Screening currently recommends that average-risk adults begin screening at age 50. A colonoscopy every 10 years or an annual fecal immunochemical test (FIT) are the top-ranked screening modalities for cancer prevention and detection, respectively. Although the FIT is a preferred method, it is important to note that this test is less sensitive and would require a follow-up colonoscopy if positive.²⁰ Colonoscopy has the ability to not only diagnose cancer, but prevent it by removing lesions from the colon that may progress to cancer in the future.^{21,22} Current adherence to any screening method has increased over the last decade and was estimated to be 62.4% in 2015.²³

In 2014, the National Colorectal Cancer Roundtable set the “80% by 2018” goal, meaning that by 2018, 80% of the eligible US population should have undergone colorectal cancer screening (<http://nccrt.org/tools/80-percent-by-2018/>). A previous study 1) used a simulation method to determine the number of additional colonoscopies and FIT tests that would need to be performed to meet this goal and 2) randomly surveyed endoscopy clinics to estimate the number of procedures currently being performed, as well as the maximum number of colonoscopies that could be performed given the clinic’s current workforce.¹⁸ However, these estimates do not take into account the fact that colonoscopies are performed in many contexts other than endoscopy clinics and by physicians with many different specialties (eg, gastroenterology, internal medicine, family medicine, etc.) and that the number of procedures performed varies significantly by physician specialty. Therefore, the true ability to meet colonoscopy screening goals must consider both the number of physicians in a given area as well as the volume of procedures those physicians are actually able to perform.

The purpose of this case study is to offer an alternative, more clinically relevant physician density to more accurately estimate physician availability for colonoscopy. We illustrate the utility of a different approach by comparing the traditional density to the alternative (volume-weighted) density of colonoscopy providers in US states and counties, overall and by urban vs rural designation. As an indicator of the predictive capacity of these measures, we calculate the association between these 2 measures and county-level cancer screening, incidence, and mortality rates, which have previously been associated with traditional physician density.^{1,10,24,25} In this study, we hypothesized that the alternative density measure for colonoscopy would have a higher correlation with cancer outcomes than the traditional density measure.

Methods

Study Population

We used the Centers for Medicare & Medicaid Services (CMS) 2014 Medicare Provider Utilization and Payment database to obtain the supply of physicians performing endoscopy in the US for this ecologic study. This database consists of individual physicians who accepted Medicare Fee-for-Service (FFS) in the US and US territories during 2014, and it contains *aggregate* information on physician/supplier Part B final-action claims for the Medicare FFS population. The database does not present each individual patient claim but

instead aggregates the number of claims per service code per provider. Each billing code is represented in the dataset, even if it pertains to a single procedure (ie, each code billed for a single colonoscopy is included). Physicians were included in our analysis if they: 1) had a practice address located in the US and a non-military location, and 2) provided greater than 10 colonoscopy procedures in 2014 (see Appendix online for a list of ICD-9, HCPCS, and CPT codes). The total number of colonoscopy procedures billed by each physician was used in the creation of our alternative volume-weighted provider density score. Data were suppressed if there were fewer than 10 beneficiaries for that provider/code combination to protect the privacy of beneficiaries. Because county was not included in the CMS Medicare Provider Utilization and Payment database, we extracted and geocoded the address of each physician (ie, street, city, state, and zip code) and matched this location to the corresponding county using ArcGIS Pro Version 2.1.3 (Esri, Redlands, CA).

GeoLytics, Inc. Estimates Professional (GeoLytics, Inc., Somerville, NJ) data were used to estimate the 2014 county population for persons aged 50 and older for the denominator for our density measures. GeoLytics, Inc. Estimates Professional creates its estimates from a combination of 2010 redistricting data and American Community Survey (US Census Bureau, Washington, DC) data, accounting for immigration and emigration data from the US Postal Service. Our denominator was purposefully chosen to include a larger group of persons than the US Preventive Services Task Force-recommended age group for colorectal cancer (CRC) screening (ie, 50–75 for average-risk persons) to ensure that our density estimates were not underestimated, given that 90% of new CRC cases are aged 50 and older.^{26,27} We also chose this age range to align with the CRC screening, incidence, and mortality rate options presented in the National Cancer Institute (NCI) State Cancer Profiles website.²⁸

Assumptions

Except for end-stage renal disease patients, Medicare services are typically reserved for the population aged 65 and older, and the CMS Medicare Provider Utilization and Payment database is limited to providers that service Medicare FFS beneficiaries. Given that 61% of new cases of CRC are in adults aged 65 and older,²⁹ we assumed that the colonoscopy providers listed in the CMS Medicare Provider Utilization and Payment database are representative of the vast majority of colonoscopy providers nationwide. We cannot assume, however, that the geographic distribution of FFS Medicare patients is proportional to the geographic distribution of all endoscopy users regardless of age or insurance type; thus, our results cannot be generalized beyond the FFS Medicare population.

Statistical Analysis

The density of physicians is traditionally measured as the number of physicians divided by a target population. The specific population used in these types of density calculations depends on the service being considered, and they can take into account who is eligible or traditionally receives the service; in this case, patients in a county aged 50 and over. This traditional density measure weighs all physicians the same, regardless of their volume of services. To calculate the alternative physician volume-weighted density, which takes into account the number of colonoscopy procedures performed in 2014, each colonoscopy billing

code was counted to create the total volume per physician. The volume was used to create the weight for each provider, W_{ijk} . Each provider, k , is nested in a county, j , which is in a state, i . Because performing at least 100 colonoscopies per year is associated with higher adenoma detection rate³⁰ and cecal intubation rate,³¹ 2 measures of colonoscopy quality, we categorized physicians providing a sufficient number of services to ensure high quality as those performing at least 100 per year. The purpose of the new weighting scheme was to down-weight providers with low volume, so that their presence in the supply chain would not signal a large availability of services. The weight applied to each provider was calculated as the individual physician volume, V_{ijk} , divided by 100 for providers that performed less than 100 endoscopy services in 2014. For those providing 100 procedures or more, the weight assigned was 1.

$$W_{ijk} = \begin{cases} V_{ijk}/100 & V_{ijk} < 100 \\ 1 & \text{otherwise} \end{cases}$$

Using this new weighted approach, the density for each county, D_{ij} , is a ratio of the sum of the weights for providers in county j from state i and the population of interest. For example, in a county where all providers performed >100 procedures, the sum would be equal to the number of providers, which is equivalent to the traditional measure. However, those counties where some providers supplied only occasional services would reflect less supply from these using the new measure. Thus, D_{ij} represents the “adjusted” number of providers that perform colonoscopy services for the target population. State- (i) and county-level (ij) volume-weighted density scores were calculated as follows, respectively.

$$D_i = \frac{\sum_j \sum_k W_{ijk}}{\text{population}_i} \quad D_{ij} = \frac{\sum_k W_{ijk}}{\text{population}_{ij}}$$

Descriptive statistics (ie, median, mean, interquartile range) and choropleth maps were used to describe the physician density (traditional and volume-weighted) for counties and states. Additionally, we compared these 2 measures as predictors of county-level colorectal cancer incidence, mortality, and screening rate obtained from 2009–2013 NCI State Cancer Profiles (ie, rates expressed per 100,000 persons aged 50+). In some states, incidence rates are completely unavailable via the NCI State Cancer Profiles database (Nevada), unavailable at the county level (Kansas and Minnesota), or do not include cases diagnosed from other states on the public website because of state regulations. In addition, if a county had an average of at most 3 deaths or cases per year, the colorectal cancer incidence and mortality data were suppressed on the NCI State Cancer Profiles website for confidentiality purposes. We also quantified the agreement of the 2 density measures using the Kappa statistic and the correlation using the Pearson correlation. We classified each density into tertiles (high, medium, and low) to quantify the agreement level using the Kappa statistic. Finally, we compared the density measures at the county level by urban vs rural designation. Rurality was based on the US Department of Agriculture 2013 Rural-Urban Continuum Codes

(RUCC) scheme for counties. Counties classified as a medium or large metro (RUCC = 1, 2, 3) are considered urban, and rural otherwise.

Results

In 2014, there were over 2 million colonoscopies provided to the Medicare population by 16,886 physicians. These physicians were present in 1,717 US counties (55% of all US counties), including the District of Columbia. The average number of colonoscopies performed per physician was 159 (SD=142), and the minimum and maximum were 11 and 2,146, respectively. Physicians located in urban counties performed on average 164 colonoscopies (SD=140), compared to 131 colonoscopies (SD=147) for physicians located in rural counties. The minimum number of colonoscopies was truncated due to the suppression of data for confidentiality purposes (ie, colonoscopy providers with 10 or fewer procedures are not listed under each respective code in the CMS dataset).

Table 1 shows the distribution of the density measures at the state level. There was a mean of 16.8 (SD=3.8) and 12.8 (SD=2.6) per 100,000 persons for the traditional and volume-weighted density, respectively. At the county level, the minimum density score (traditional and volume-weighted) was zero; in fact, almost half (n=1,424) of all US counties had zero physicians performing >10 colonoscopies in 2014. Warren County, Ohio, had the lowest non-zero volume-weighted density per 100,000 persons (0.16), and Pinal County, Arizona, had the lowest non-zero traditional density (0.61), both of which had only one physician. Fredericksburg city, Virginia, had the highest volume-weighted density (195), and Mitchell County, Kansas, had the highest traditional density (231).

In counties with at least 1 physician, the 2 measures show some agreement overall [Kappa = 51.5% (48.2%, 54.8%)]. When all counties are included, including those with zero physicians, agreement is improved [Kappa = 83% (81%, 85%)], as expected. The highest disagreement between density measures was observed in the Western and Midwestern portion of the US.

Physicians providing >10 colonoscopies in 2014 were present in 71% of urban and 45% of rural counties. Table 2 shows the distribution of the 2 density measures by rurality. Urban counties had a higher median traditional and volume-weighted density compared to rural counties ($P < .001$). While the confidence intervals overlap, the volume-weighted density had a slightly higher correlation with the county-level incidence, mortality, and screening rate than the traditional density, with both measures showing higher density being associated with higher screening rates (Table 3). In a secondary non-parametric analysis, the Spearman correlation between the 2 density measures and CRC outcomes maintained the same direction with similar values (data not shown). The association between the volume-weighted and traditional density measures was similar for state-level incidence and mortality; however, the association revealed that higher density was associated with worse outcomes. The county-level association between density and CRC incidence and mortality, although statistically significant, was close to zero. The correlation for county-level outcomes was approximately the same for urban and rural counties (data not shown).

Discussion

This study presents an alternative method of calculating physician density for a specific service, with the example of colonoscopy which utilized the volume of procedures performed by physicians. The center and spread of the weighted density distribution are lower and tighter than those of the traditional density measure, as expected. Approximately 96% of counties with the highest disagreement (high traditional, low volume-weighted density) were rural and were located mostly in the Western and Midwestern areas of the country. Although the 2 density measures were significantly different, they have some agreement overall. A high volume-weighted density implies that the county or state also has a high traditional density (ie, most or all providers in the area provide 100+ procedures/year).

In comparison to rural counties, urban counties showed a higher concentration of colonoscopy providers overall, which is consistent with current literature about geographic variation in colorectal cancer screening and treatment providers.^{32,33} The stark difference is due to the large number of rural counties, mostly in the Midwestern and Western region, that had no providers. When comparing the density measures within rural counties, the difference between the mean and median traditional density values (10.69) were noticeably larger than the difference in the volume-weighted mean and median (6.34) counterparts. However, in urban counties, the difference between the mean and median were about the same for the 2 density measures (traditional: 1.82 vs weighted: 1.79). This highlights the fact that most of the urban counties had physicians that performed >10 colonoscopies/year. The small difference between the median density measures also highlight that physicians in urban counties are more likely to perform at least 100 colonoscopies per year. In practice, it may be feasible for colonoscopy providers in rural counties to perform more procedures if demand for services increased or physicians dedicated more of their time to this service line. Previous research has shown that colorectal cancer screening rates in rural areas are significantly lower than in their urban counterparts.^{34–36} Future research to determine the unrealized capacity (ie, achievable procedure volume per physician) in rural areas is therefore warranted.

Incorporating the volume of physicians resulted in slightly improved associations between provider density and colorectal cancer screening rates, particularly at the state level. The associations between county provider density and colorectal cancer incidence and mortality were very low, but they were in the expected negative direction, unlike the state-level correlations, which were in the positive direction. This discrepancy may be due to aggregation of results over large areas.

Although this study provides an example of how sensitive measures are to the definitions of supply and demand, we note that county boundaries do not truly separate populations receiving services. Therefore, this method can be improved by incorporating spatial accessibility to capture the spillover of populations that receive services in other geographic locations. The primary purpose of the data source used (ie, CMS Medicare Payment and Utilization Database) is billing and transparency; conclusions should be taken with caution when using the same source for research. Because of the limitations of the data source, we

could not accurately determine the purpose of the colonoscopy procedures performed by each provider (screening, diagnostic or surveillance) or the total number of unique patients served by each provider, nor could we account for procedure volume in persons with insurance coverage other than FFS Medicare. Because colonoscopy is most often performed in older persons, however, we feel confident that the majority of colonoscopy providers were captured in our database and that the procedure volume recorded for each physician is likely reflective of their relative procedure volume among the Medicare FFS population of persons aged 50+. Another limitation of the dataset is the masking of physicians who performed 10 or fewer colonoscopies per a specific procedure code. While this may affect the traditional density measure, the volume-weighted density would remain relatively the same due to the low weight assigned to these physicians. We also caution against using CMS data to create volume-weighted density scores for procedures that are primarily performed in younger persons or are performed infrequently in general. Alternative data sources such as all-payer databases (eg, MarketScan (IBM, Armonk, NY)) or inpatient/outpatient surgery discharge records (eg, Healthcare Cost and Utilization Project Database, Agency for Healthcare Research and Quality, Rockville, MD) would be more appropriate in such scenarios.

Although this case study focused on colonoscopy providers, the density calculation formula developed here may be useful for quantifying density of providers for other service types. Using a reliable data source on provider location and procedure volume, this formula can offer a more realistic picture of supply for a given population than the traditional density measure alone. In conclusion, this case study sought to improve the way density is measured to increase the predictive ability of this commonly used measure on CRC outcomes; in this case, the most substantial improvement was in the correlation between state-level density and the CRC screening rate. This work lays the foundation for future studies aiming to determine geographic variation in unrealized capacity for colorectal cancer screening, and to explore the association of physician availability with cancer-related outcomes.

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Appendix

Appendix

Centers for Medicare & Medicaid Services (CMS) 2014 Medicare Provider Utilization and Payment database colonoscopy procedure codes

HCPSC Code	Description
44388	Diagnostic examination of large bowel using an endoscope
44389	Biopsy of large bowel using an endoscope which is inserted through abdominal opening into large bowel
44392	Removal of polyps or growths of large bowel using an endoscope which is inserted through abdominal opening into large bowel

HCPSC Code	Description
44394	Removal of large bowel polyps or growths using an endoscope
45378	Diagnostic examination of large bowel using an endoscope
45379	Removal of foreign body in large bowel using an endoscope
45380	Biopsy of large bowel using an endoscope
45381	Injections of large bowel using an endoscope
45382	Control of bleeding in large bowel using an endoscope
45383	Removal of polyps or growths in large bowel using an endoscope
45384	Removal of polyps or growths in large bowel using an endoscope
45385	Removal of polyps or growths of large bowel using an endoscope
45391	Ultrasound examination of large bowel using an endoscope
G0105	Colorectal cancer screening; colonoscopy on individual at high risk
G0121	Colorectal cancer screening; colonoscopy on individual not meeting criteria for high risk

References

1. Ananthakrishnan AN, Hoffmann RG, Saeian K. Higher physician density is associated with lower incidence of late-stage colorectal cancer. *Journal of general internal medicine*. 2010;25:1164–1171. [PubMed: 20658268]
2. Ananthakrishnan AN, McGinley EL, Binion DG, Saeian K. Physician density and hospitalization for inflammatory bowel disease. *Inflammatory bowel diseases*. 2011;17:633–638. [PubMed: 20848540]
3. Campbell RJ, Ramirez AM, Perez K, Roetzheim RG. Cervical cancer rates and the supply of primary care physicians in Florida. *Family medicine*. 2003;35:60–64. [PubMed: 12564867]
4. Ho MY, Al-Barrak J, Peixoto RD, Cheung WY. The association between county-level surgeon density and esophageal and gastric cancer mortality. *Journal of gastrointestinal cancer*. 2014;45:487–493. [PubMed: 25342577]
5. Kociol RD, Greiner MA, Fonarow GC, et al. Associations of patient demographic characteristics and regional physician density with early physician follow-up among medicare beneficiaries hospitalized with heart failure. *The American journal of cardiology*. 2011;108:985–991. [PubMed: 21791327]
6. Plascak JJ, Fisher JL, Paskett ED. Primary care physician supply, insurance type, and late-stage cancer diagnosis. *American journal of preventive medicine*. 2015;48:174–178. [PubMed: 25441233]
7. Roetzheim RG, Pal N, van Durme DJ, et al. Increasing supplies of dermatologists and family physicians are associated with earlier stage of melanoma detection. *Journal of the American Academy of Dermatology*. 2000;43:211–218. [PubMed: 10906640]
8. Sundmacher L, Busse R. The impact of physician supply on avoidable cancer deaths in Germany. A spatial analysis. *Health policy (Amsterdam, Netherlands)*. 2011;103:53–62.
9. Yao N, Foltz SM, Odisho AY, Wheeler DC. Geographic analysis of urologist density and prostate cancer mortality in the United States. *PloS one* 2015;10:e0131578. [PubMed: 26110832]
10. Roetzheim RG, Pal N, Gonzalez EC, et al. The effects of physician supply on the early detection of colorectal cancer. *The Journal of family practice*. 1999;48:850–858. [PubMed: 10907621]
11. Hoffman RM, Stone SN, Herman C, et al. New Mexico's capacity for increasing the prevalence of colorectal cancer screening with screening colonoscopies. *Preventing chronic disease*. 2005;2:A07.
12. Brown T, Lee JY, Park J, et al. Colorectal cancer screening at community health centers: A survey of clinicians' attitudes, practices, and perceived barriers. *Preventive medicine reports*. 2015;2:886–891. [PubMed: 26844165]

13. Barzi A, Klein EA, Daneshmand S, Gill I, Quinn DI, Sadeghi S. Access to high-volume surgeons and the opportunity cost of performing radical prostatectomy by low-volume providers. *Urologic oncology*. 2017;35:459 e15-e24.
14. DesRoches CM, Gaudet J, Perloff J, Donelan K, Iezzoni LI, Buerhaus P. Using Medicare data to assess nurse practitioner-provided care. *Nursing outlook*. 2013;61:400–407. [PubMed: 23870733]
15. Mobley LR, Amaral P, Kuo TM, Zhou M, Bose S. Medicare modernization and diffusion of endoscopy in FFS medicare. *Health economics review*. 2017;7:13. [PubMed: 28281245]
16. Bibbins-Domingo K, Grossman DC, Curry SJ, et al. Screening for Colorectal Cancer: US Preventive Services Task Force Recommendation Statement. *Jama*. 2016;315:2564–2575. [PubMed: 27304597]
17. Chang M, Schroy PC, 3rd. Endoscopic colorectal cancer screening--can supply meet demand? *Gastroenterology*. 2004;126:1482–1485. [PubMed: 15131811]
18. Joseph DA, Meester RG, Zauber AG, et al. Colorectal cancer screening: Estimated future colonoscopy need and current volume and capacity. *Cancer*. 2016;122:2479–2486. [PubMed: 27200481]
19. Brown ML, Klabunde CN, Mysliwiec P. Current capacity for endoscopic colorectal cancer screening in the United States: data from the National Cancer Institute Survey of Colorectal Cancer Screening Practices. *The American journal of medicine*. 2003;115:129–133. [PubMed: 12893399]
20. American Gastroenterological Association. Task force presents new ranking of colorectal cancer screening tests; 2017 Available at: http://www.gastro.org/press_releases/task-force-presents-new-ranking-of-colorectal-cancer-screening-tests. Accessed March 15 2017.
21. Xirasagar S, Hurley TG, Sros L, et al. Quality and Safety of Screening Colonoscopies Performed by Primary Care Physicians With Standby Specialist Support. *Med Care*. 2010;48(8):703–709. www.jstor.org/stable/25701524. [PubMed: 20613663]
22. Young PE, Womeldorph CM. Colonoscopy for colorectal cancer screening. *Journal of Cancer*. 2013;4:217–226. [PubMed: 23459594]
23. White A, Thompson TD, White MC, et al. Cancer Screening Test Use - United States, 2015. *MMWR Morbidity and mortality weekly report*. 2017;66:201–206. [PubMed: 28253225]
24. Ferrante JM, Gonzalez EC, Pal N, Roetzheim RG. Effects of physician supply on early detection of breast cancer. *The Journal of the American Board of Family Practice*. 2000;13:408–414. [PubMed: 11117337]
25. Roetzheim RG, Gonzalez EC, Ramirez A, Campbell R, van Durme DJ. Primary care physician supply and colorectal cancer. *The Journal of family practice*. 2001;50:1027–1031. [PubMed: 11742602]
26. American Cancer Society. Colorectal Cancer Facts & Figures 2014–2016 Available at: <https://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/colorectal-cancer-facts-and-figures/colorectal-cancer-facts-and-figures-2014-2016.pdf>. Accessed March 15, 2017.
27. Myers EA, Feingold DL, Forde KA, Arnell T, Jang JH, Whelan RL. Colorectal cancer in patients under 50 years of age: a retrospective analysis of two institutions' experience. *World journal of gastroenterology*. 2013;19:5651–5657. [PubMed: 24039357]
28. National Cancer Institute. State Cancer Profiles. Available at: <https://statecancerprofiles.cancer.gov/index.html>. Accessed March 15 2017.
29. Siegel R, Desantis C, Jemal A. Colorectal cancer statistics, 2014. *CA: a cancer journal for clinicians*. 2014;64:104–117. [PubMed: 24639052]
30. Bhangu A, Bowley DM, Horner R, Baranowski E, Raman S, Karandikar S. Volume and accreditation, but not specialty, affect quality standards in colonoscopy. *The British journal of surgery*. 2012;99:1436–1444. [PubMed: 22961527]
31. Wexner SD, Garbus JE, Singh JJ. A prospective analysis of 13,580 colonoscopies. Reevaluation of credentialing guidelines. *Surgical endoscopy*. 2001;15:251–261. [PubMed: 11344424]
32. Aboagye JK, Kaiser HE, Hayanga AJ. Rural-Urban Differences in Access to Specialist Providers of Colorectal Cancer Care in the United States: A Physician Workforce Issue. *JAMA surgery*. 2014;149:537–543. [PubMed: 24740165]

33. Blankart CR. Does healthcare infrastructure have an impact on delay in diagnosis and survival? *Health policy (Amsterdam, Netherlands)*. 2012;105:128–137.
34. Cole AM, Jackson JE, Doescher M. Urban-rural disparities in colorectal cancer screening: cross-sectional analysis of 1998–2005 data from the Centers for Disease Control’s Behavioral Risk Factor Surveillance Study. *Cancer medicine*. 2012;1:350–356. [PubMed: 23342284]
35. Cole AM, Jackson JE, Doescher M. Colorectal cancer screening disparities for rural minorities in the United States. *Journal of primary care & community health*. 2013;4:106–111.
36. Bennett KJ, Probst JC, Bellinger JD. Receipt of cancer screening services: surprising results for some rural minorities. *J Rural Health*. 2012;28(1):63–72. [PubMed: 22236316]

Table 1.

Traditional and Volume-weighted Physician Density per 100,000 Persons Aged 50+, by US State

State	Weighted Density	Traditional Density	Absolute Diff.	Region
United States	24.70	15.53	9.16	
District of Columbia	19.71***	23.58	3.87	S
South Dakota	18.64	27.76***	9.12	M
Delaware	17.24	22.72	5.48	S
Rhode Island	16.65	20.92	4.27	NE
North Dakota	16.35	23.28	6.93	M
Massachusetts	16.15	19.59	3.44	NE
Connecticut	15.48	19.53	4.05	NE
Kentucky	15.27	19.84	4.57	S
Nebraska	15.27	22.51	7.24	M
New Jersey	15.17	17.79	2.62	NE
Louisiana	15.01	20.47	5.47	S
Maryland	14.06	17.26	3.20	S
South Carolina	13.86	17.65	3.79	S
New Hampshire	13.84	15.99	2.15	NE
Alabama	13.82	17.10	3.28	S
Missouri	13.60	17.47	3.86**	M
Pennsylvania	13.56	18.18	4.62	NE
West Virginia	13.55	19.48	5.93	S
Indiana	13.18	16.68	3.50	M
Maine	13.08	15.99	2.92	NE
Kansas	13.01	20.88	7.87	M
New York	12.93	18.29	5.36	NE
Ohio	12.91	17.22	4.32	M
Mississippi	12.86	15.08	2.22	S
Oklahoma	12.83	16.78**	3.94	S
Illinois	12.83**	15.95	3.12	M
Iowa	12.72	18.26	5.53	M
North Carolina	12.70	15.37	2.66	S
Tennessee	12.57	15.50	2.92	S
Arkansas	12.56	16.94	4.38	S
Michigan	12.41	16.34	3.93	M
Vermont	12.03	15.00	2.97	NE
Virginia	11.95	14.37	2.42	S
Wyoming	11.88	22.48	10.59***	W
Wisconsin	11.86	16.43	4.58	M
Georgia	11.34	14.65	3.32	S
Florida	11.30	13.55	2.25	S

State	Weighted Density	Traditional Density	Absolute Diff.	Region
Washington	11.25	14.06	2.81	W
Utah	11.21	16.73	5.52	W
Alaska	10.88	20.65	9.78	W
Minnesota	10.87	18.52	7.65	M
Idaho	10.78	14.44	3.65	W
Texas	10.65	13.57	2.91	S
Oregon	10.50	14.84	4.34	W
Arizona	10.28	12.73	2.44	W
New Mexico	9.99	12.48	2.49	W
Colorado	9.74	12.58	2.83	W
Montana	8.61	12.48	3.87	W
California	8.22	10.08	1.86	W
Nevada	7.30	8.38*	1.08*	W
Hawaii	7.08*	9.55	2.47	W

Notes: The data is ranked by the volume-weighted density. The maximum (***), median (**), and minimum (*) for each rate is in bold and symbolized appropriately. Traditional density is measured by the number of physicians performing colonoscopy to CMS beneficiaries in a state divided by the population aged 50+. Volume-weighted density is measured by the weighted sum of physicians performing colonoscopy to CMS beneficiaries in a state divided by the population aged 50+.

Table 2.**Median and Mean Physician Density by Urban-Rural Status in US Counties**

	Median			Mean		
	Overall	Urban	Rural	Overall	Urban	Rural
Traditional Density	6.98 (17.8)	11.05 (18.6)	0 (17.2)*	11.50 (16.7)	12.87 (15.7)	10.69 (17.1)*
Weighted Density	3.20 (12.8)	8.11 (14.6)	0 (11.1)*	7.66 (11.1)	9.91 (12.6)	6.34 (9.9)*

Notes: The value in the parentheses shows the interquartile range of the distribution for the median and the standard deviation for the mean. The *P* values for the difference in median density by urban/rural status are from the nonparametric Wilcoxon Rank Sum Test; the distributions of densities are skewed. The *P* value for the mean is reflected from a t-test (**P* < .001). Traditional density is measured by the number of physicians performing colonoscopy to CMS beneficiaries in a state divided by the population aged 50+. Volume-weighted density is measured by the weighted sum of physicians performing colonoscopy to CMS beneficiaries in a state divided by the population aged 50+.

Table 3.

Pearson Correlations Between Physician Density Measures and CRC Screening, Incidence and Mortality at the State and County Level

	Traditional Density	Weighted Density
	<i>r</i> (<i>P</i> value)	<i>r</i> (<i>P</i> value)
<i>CRC Screening Rate</i>		
State level	0.17 (.229)	0.33 (.017)
County level	0.20 (<.001)	0.24 (<.001)
<i>CRC Incidence</i>		
State level	0.41 (.003)	0.38 (.006)
County level	−0.04 (.040)	−0.06 (.001)
<i>CRC Mortality</i>		
State level	0.26 (.069)	0.30 (.033)
County level	−0.09 (< .001)	−0.15 (< .001)

Notes: CRC screening, incidence, and mortality rates based on population aged 50+. CRC screening is based on modeled estimates from 2008–2010, and incidence and mortality rates are based on 2009–2013 data from NCI State Cancer Profiles. Traditional density is measured by the number of physicians performing colonoscopy to CMS beneficiaries in a state divided by the population aged 50+. Volume-weighted density is measured by the weighted sum of physicians performing colonoscopy to CMS beneficiaries in a state divided by the population aged 50+.