Article

Comparing magnetic resonance imaging and computed tomography machine accessibility among urban and rural county hospitals

Benjamin T. Burdorf

Northeast Ohio Medical University, Rootstown, OH, USA

Abstract

Background: In 2019, Navigant Healthcare published research showing that 1 in 5 rural hospitals in Minnesota are at risk of closing as they are not financially sustainable. With 26.7% of Minnesota’s population being rural, this is particularly worrisome. A substantial cost to rural hospitals is affording the installation, maintenance, and operation of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) machines. In light of the serious pressures on rural hospitals, the aim of this paper is to investigate if a disparity exists in MRI and CT machine accessibility among Minnesota’s urban and rural county hospitals.

Design and Methods: Hospitals of Minnesota were contacted and asked how many MRI and CT machines they carried at their facility. This information was compiled in an excel sheet and cross referenced to the county it resided along with the counties: population, rural-urban commuting area (RUCA) classification and land area in square mile. Results: It was found that the state of Minnesota compared well to the national average in terms of persons and square mileage per MRI and CT machine. When comparing counties of Minnesota by their RUCA classification, a disparity is found in rural counties with regards to square mileage per CT and MRI machine.

Conclusions: With distance for service creating a barrier to accessibility, rural county residents would benefit from more in-hospital MRI and CT machines. With these findings, it is pertinent further research is conducted to investigate the potential vulnerability of other rural populations with regards to accessibility to radiologic resources.

Introduction

The Association of American Medical Colleges published an article in 2017 highlighting some of the health disparities facing the rural United States. It showed that rural America faces higher disease incidence in conjunction with worse outcomes when compared to their urban and suburban counterparts. When investigating these differences, it was found that difficulties in accessing healthcare resources was a major contributing factor. With the United States Census reporting that 19.3% of the country’s population resides in a rural area, this issue should be given attention. In states like Minnesota, where 26.7% of its population is rural, there is more concern with regards to vulnerability to these health disparities. With its large rural population, Minnesota has 78 Critical Access Hospitals (CAH), the third highest in the nation. Even with the government assistance to CAH, in 2019, Navigant Healthcare published research showing that 1 in 5 rural hospitals in Minnesota are at risk of closing as they are not financially sustainable. Although there are many financial hurdles facing rural hospitals, one that is particularly substantial is affording the installation, maintenance and operation of Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) machines. Despite these challenges, there is no debate that it is fundamental we do our best provide the same quality of healthcare to all individuals.

Accessibility/financial strain on rural hospitals and consequent lack of radiologic resources is likely contributory to the higher disease incidence and worse outcomes of rural American populations when compared to their more urban counterparts.

Design and Methods

All Minnesota hospitals listed on mnhospitals.org were contacted through their general line. Hospitals that provided services to an exclusive subset of the population, such as Native Americans, were excluded. Once either a technologist of the radiology department, or the Director of Radiology for the hospital was reached, the purpose of the research was explained. It was then inquired how many MRI and CT machines they carried at their facility. For both machines, it was always specified whether the unit was part of a mobile service, or permanent. Once this information was obtained for each hospital it was compiled in an excel sheet and cross referenced to the county it resided along with the counties: population, RUCA classification (Figure 1) and land area in square mile. With this data, persons per MRI and CT machine were generated for each county. In addition, square mileage per MRI and CT machine were calculated for each county (Table 1). Mobile units were excluded (Figure 2). Mapping of these densities (Figures 3 and 4) was done with Adobe Illustrator. Percentile standings were calculated among counties with MRI and CT machines using the percentile function in Excel. The data
was further analyzed by grouping counties into their respective RUCA classifications (Figure 1) and seeing how they compared collectively to one another. This was done in bar graph format as seen in Figure 5 which was also generated by Excel. The state of Minnesota, as a whole, was also able to be compared to the United States using data from the Organization for Economic Co-operation and Development (OECD).

Table 1. In-hospital magnetic resonance imaging and computed tomography machine data by Minnesota County and rural-urban area classification using their respective populations and land areas.

| RUCA Class | County         | Population | Square Miles | MRIs | CTs | Persons/MRI | Square Miles/MRI | Persons/CT | Square Miles/CT |
|------------|----------------|------------|--------------|------|-----|-------------|-----------------|------------|----------------|
| A          | Aitkin         | 15870      | 1822         | 1    | 1   | 15870       | 1822           | 15870      | 1822           |
| A          | Big Stone      | 4993       | 499          | 0    | 2   | N/A         | N/A             | 2497       | 250            |
| A          | Cook           | 5462       | 1452         | 0    | 1   | N/A         | N/A             | 5462       | 1452           |
| A          | Grant          | 5967       | 548          | 0    | 1   | N/A         | N/A             | 5967       | 548            |
| A          | Kittson        | 4299       | 1099         | 0    | 1   | N/A         | N/A             | 4299       | 1099           |
| A          | Lac qui Parle   | 6629       | 765          | 0    | 2   | N/A         | N/A             | 3315       | 383            |
| A          | Lake of the Woods | 3798   | 1298         | 0    | 1   | N/A         | N/A             | 3798       | 1298           |
| A          | Lincoln        | 5648       | 537          | 0    | 2   | N/A         | N/A             | 2824       | 268            |
| A          | Mahnomen       | 5529       | 558          | 0    | 1   | N/A         | N/A             | 5529       | 558            |
| A          | Murray         | 8222       | 705          | 1    | 1   | 8222        | 705             | 8222       | 705            |
| A          | Norman         | 6367       | 873          | 0    | 1   | N/A         | N/A             | 6367       | 873            |
| A          | Red Lake       | 4030       | 432          | 0    | 0   | N/A         | N/A             | N/A        | N/A            |
| A          | Renville       | 14588      | 983          | 1    | 1   | 14588       | 983             | 14588      | 983            |
| A          | Traverse       | 3263       | 574          | 0    | 1   | N/A         | N/A             | 3263       | 574            |
| B          | Beltrami       | 47184      | 2505         | 2    | 2   | 23592       | 1252           | 23592      | 1252           |
| B          | Brown          | 25119      | 611          | 1    | 2   | 25119       | 611             | 12560      | 306            |
| B          | Cass           | 29754      | 2022         | 0    | 0   | N/A         | N/A             | N/A        | N/A            |
| B          | Chippewa       | 11858      | 581          | 1    | 1   | 11858       | 581             | 11858      | 581            |
| B          | Clearwater     | 8808       | 999          | 0    | 1   | N/A         | N/A             | 8808       | 999            |
| B          | Cottonwood     | 11216      | 639          | 0    | 2   | N/A         | N/A             | 5608       | 319            |
| B          | Crow Wing      | 65274      | 999          | 2    | 3   | 32637       | 500             | 21758      | 333            |
| B          | Douglas        | 38220      | 637          | 2    | 1   | 19110       | 319             | 38220      | 637            |
| B          | Faribault      | 13580      | 712          | 0    | 1   | N/A         | N/A             | 13580      | 712            |
| B          | Freeborn       | 30364      | 707          | 0    | 0   | N/A         | N/A             | N/A        | N/A            |
| B          | Hubbard        | 21494      | 926          | 1    | 1   | 21494       | 926             | 21494      | 926            |
| B          | Itasca         | 45203      | 2668         | 2    | 3   | 22602       | 1334            | 15068      | 889            |
| B          | Jackson        | 9858       | 703          | 0    | 1   | N/A         | N/A             | 9858       | 703            |
| B          | Kandiyohi      | 43193      | 797          | 1    | 1   | 43193       | 797             | 43193      | 797            |
| B          | Koochiching    | 12430      | 3104         | 1    | 1   | 12430       | 3104            | 12430      | 3104           |
| B          | Lake           | 10632      | 2109         | 0    | 1   | N/A         | N/A             | 10632      | 2109           |
| B          | Lyon           | 25635      | 715          | 1    | 2   | 25635       | 715             | 12818      | 357            |
| B          | Martin         | 19752      | 712          | 0    | 0   | N/A         | N/A             | N/A        | N/A            |
| B          | Meeker         | 23256      | 608          | 1    | 1   | 23256       | 608             | 23256      | 608            |
| B          | Morrison       | 33368      | 1125         | 1    | 1   | 33368       | 1125            | 33368      | 1125           |
| B          | Nobles         | 21976      | 715          | 1    | 1   | 21976       | 715             | 21976      | 715            |
| B          | Otter Tail     | 58734      | 1972         | 2    | 2   | 29367       | 986             | 29367      | 986            |
| B          | Pennington     | 14355      | 617          | 1    | 1   | 14355       | 617             | 14355      | 617            |
| B          | Pipestone      | 9132       | 465          | 1    | 1   | 9132        | 465             | 9132       | 465            |
| B          | Pope           | 11139      | 670          | 1    | 1   | 11139       | 670             | 11139      | 670            |
| B          | Redwood        | 15204      | 879          | 1    | 1   | 15204       | 879             | 15204      | 879            |
| B          | Roseau         | 15242      | 1672         | 1    | 1   | 15242       | 1672            | 15242      | 1672           |
| B          | Steele         | 37112      | 430          | 1    | 1   | 37112       | 430             | 37112      | 430            |
| B          | Stevens        | 9766       | 564          | 1    | 1   | 9766        | 564             | 9766       | 564            |
| B          | Swift          | 9367       | 742          | 0    | 2   | N/A         | N/A             | 4684       | 371            |

To be continued on next page
Results

Beginning with CT machine accessibility, of the 87 counties in Minnesota, 14 counties did not have an in-hospital CT machine. Based off of RUCA classifications (Figure 1), 4 were urban, 6 were mixed urban/town/rural, 3 were mixed town/rural and 1 was rural (Figure 3). The state of Minnesota averaged slightly more people per CT machine at 36,180 in comparison to the national average of 35,714. For Minnesota, the urban counties averaged 65,841, mixed urban/town/rural counties averaged 27,879, mixed town/rural counties averaged 18,034 and rural counties averaged 5,917 (Figure 5). For county square mileage per CT machine, the state of Minnesota averaged 607 in comparison to the national average of 385. For Minnesota, the urban counties averaged 119, mixed

Table 1. Continued from previous page.

| RUCA Class | County         | Population | Square Miles | MRIs | CTs | Persons/MRI | Square Miles | Persons/CT | Square Miles/CT |
|------------|----------------|------------|--------------|------|-----|-------------|--------------|------------|-----------------|
| B          | Todd           | 24665      | 945          | 2    | 2   | 12333       | 472          | 12333     | 472             |
| B          | Wadena         | 13744      | 536          | 1    | 1   | 13744       | 536          | 13744     | 536             |
| B          | Watonwan       | 10923      | 435          | 0    | 1   | N/A         | N/A          | N/A       | N/A             |
| B          | Wilkin         | 6226       | 751          | 1    | 1   | 6226        | 751          | 6226      | 751             |
| B          | Yellow Medicine| 9729       | 759          | 0    | 2   | N/A         | N/A          | N/A       | N/A             |
| C          | Becker         | 34545      | 1315         | 1    | 1   | 34545       | 1315         | 34545     | 1315            |
| C          | Benton         | 40895      | 408          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| C          | Carlton        | 35935      | 861          | 2    | 2   | 17968       | 431          | 17968     | 431             |
| C          | Fillmore       | 21060      | 861          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| C          | Goodhue        | 46449      | 757          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| C          | Houston        | 18626      | 552          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| C          | Isanti         | 40566      | 436          | 1    | 1   | 40566       | 436          | 40566     | 436             |
| C          | Kanabec        | 16310      | 522          | 1    | 1   | 16310       | 522          | 16310     | 522             |
| C          | Le Sueur       | 28894      | 449          | 0    | 1   | N/A         | N/A          | N/A       | N/A             |
| C          | McLeod         | 35963      | 491          | 2    | 2   | 17982       | 246          | 17982     | 246             |
| C          | Marshall       | 9342       | 1775         | 0    | 1   | N/A         | N/A          | N/A       | N/A             |
| C          | Mille Lacs     | 26227      | 572          | 1    | 2   | 26227       | 572          | 13114     | 286             |
| C          | Mower          | 40124      | 711          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| C          | Nicollet       | 34323      | 448          | 0    | 1   | N/A         | N/A          | N/A       | N/A             |
| C          | Pine           | 28526      | 1411         | 0    | 1   | N/A         | N/A          | 28526     | 1411            |
| C          | Polk           | 31524      | 1971         | 1    | 2   | 31524       | 1971         | 1971      | 986             |
| C          | Rice           | 68853      | 496          | 1    | 1   | 68853       | 496          | 68853     | 496             |
| C          | Rock           | 9359       | 482          | 0    | 0   | N/A         | N/A          | 9359      | 482             |
| C          | St. Louis      | 199661     | 6247         | 8    | 12  | 24958       | 781          | 16638     | 521             |
| C          | Sibley         | 14899      | 589          | 0    | 1   | N/A         | N/A          | 14899     | 589             |
| C          | Steele         | 160211     | 1343         | 5    | 7   | 32042       | 269          | 22887     | 192             |
| C          | Wabasha        | 21614      | 523          | 0    | 0   | N/A         | N/A          | 21614     | 523             |
| C          | Waseca         | 18648      | 423          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| C          | Winona         | 50830      | 626          | 1    | 1   | 50830       | 626          | 50830     | 626             |
| C          | Wright         | 138331     | 661          | 2    | 3   | 69266       | 331          | 46177     | 220             |
| D          | Anoka          | 362648     | 423          | 2    | 3   | 181324      | 212          | 120883    | 141             |
| D          | Blue Earth     | 68583      | 748          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| D          | Carver         | 107179     | 354          | 1    | 2   | 107179      | 354          | 53590     | 177             |
| D          | Chisago        | 56613      | 415          | 2    | 2   | 28307       | 207          | 28307     | 207             |
| D          | Clay           | 64591      | 1045         | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| D          | Dakota         | 433902     | 562          | 3    | 4   | 144434      | 187          | 108326    | 141             |
| D          | Dodge          | 20943      | 439          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| D          | Hennepin       | 1279981    | 554          | 28   | 28  | 45714       | 20           | 45714     | 20              |
| D          | Olmsted        | 160431     | 653          | 1    | 1   | 160431      | 653          | 160431    | 653             |
| D          | Ramsey         | 558248     | 152          | 10   | 10  | 55825       | 15           | 55825     | 15              |
| D          | Scott          | 148458     | 356          | 1    | 2   | 148458      | 356          | 74229     | 178             |
| D          | Sherburne      | 97520      | 433          | 0    | 0   | N/A         | N/A          | N/A       | N/A             |
| D          | Washington     | 262748     | 384          | 2    | 3   | 131374      | 192          | 87583     | 128             |

A= Rural Counties, B= Mixed Town/Rural Counties, C= Mixed Urban/Town/Rural Counties and D= Urban Counties.
urban/town/rural counties averaged 594, mixed town/rural counties averaged 819 and rural counties averaged 759 (Figure 5). Data by county for persons per CT machine and square mileage per CT machine can be seen in Figure 3 and Table 1.

Shifting to MRI machine accessibility, of the 87 counties in Minnesota, 39 counties did not have an in-hospital MRI machine. Based from RUCA classifications (Figure 1), 4 were urban, 13 were mixed urban/town/rural, 11 were mixed town/rural and 11 were rural (Figure 4). Among these 39 counties, 14 utilized a hospital mobile MRI service (Figure 2). The state of Minnesota averaged slightly less people per MRI machine at 52,113 in comparison to the national average of 55,249. For Minnesota, the urban counties averaged 72,425, mixed urban/town/rural counties averaged 45,035, mixed town/rural counties averaged 26,450 and rural counties averaged 31,555 (Figure 5). For county square mileage per MRI machine, the state of Minnesota averaged 731 in comparison to the national average of 595. For Minnesota, the urban counties averaged 130, mixed urban/town/rural counties averaged 959, mixed town/rural counties averaged 1,201 and rural counties averaged 4,048 (Figure 5). Data by county for persons per MRI machine and square mileage per MRI machine can be seen in Figure 4 and Table 1.

Discussion and Conclusions

There are no set guidelines in terms of the recommended MRI or CT machine quantity per persons or square mileage. This raises the question as to how it can be determined what an appropriate value for adequate representation in a given population. For guidance, data was pulled from the OECD to generate national average values to place state level statistics into perspective.

Minnesota as a whole compared quite well to the national average with regards to MRI and CT machines per persons and square mileage (Figure 5). When looking at the RUCA classifications for persons per MRI and CT machine, the data showed that rural pre-

![Figure 1. Minnesota County map with Rural-Urban Commuting Area (RUCA) classifications.](image-url)

![Figure 2. Minnesota County map and table highlighting usage of mobile magnetic resonance imaging services.](image-url)
dominant populations were better represented when compared to more urban populations (Figure 5). Unfortunately, this statistic is misleading and does not highlight the accessibility issue that exists. Although rural populations do have less people per MRI and CT machine, the distance to these resources is what serves as the barrier. This is shown when we look at square mileage per MRI and CT machines by RUCA classification. For square mileage per CT machine, Minnesota’s rural counties and mixed town/rural counties had values of 759 and 819 respectively. These values are essentially double the national average of 385 and substantially greater than the 119 square miles per CT machine seen in Minnesota’s urban counties (Figure 5). Provided CT machines play a vital role in acute care, the value in their accessibility cannot be understated. For MRIs, the greatest disparity of this research is shown. The average square mileage per MRI machine in rural counties of Minnesota is 4,048. When you compare this to the national average of 595 and 130 seen in Minnesota’s urban counties, it is a 680% and 3,114% increase respectively. Granted, this misrepresentation is in part addressed by mobile MRI services, when talking to hospitals utilizing mobile MRI’s the availability ranged anywhere from 3 days a week to once every 2 weeks. This means the majority of rural patients have to arrange another visit or, with more time sensitive health concerns, travel to a different health facility. These serve as inadvertent barriers to people in rural communities. As reported by the Association of American Medical Colleges, the long distances and time required to receive health services often result in those who need care to delay or avoid it altogether. If a rural patient has to make another appointment for mobile MRI services, they must again face the challenges they overcame for their initial visit. For these reasons, rural hospitals...

Figure 3. Minnesota County maps with color spectrums illustrating the percentile performance among counties within hospital computed tomography (CT) machines by persons per CT machine (left) and square mileage per CT machine (right).

Figure 4. Minnesota County Maps with color spectrums illustrating the percentile performance among counties within hospital magnetic resonance imaging (MRI) machines by persons per MRI machine (left) and square mileage per MRI machine (right).
would benefit if they were able to implement a permanent MRI machine in place of mobile services.

Potential sources of error in this research include inaccurate information relayed by contacted radiology technologists. There were a few instances where when asked how many MRI and CT machines were carried at their facility, technologists provided answers that also included the machines at hospital affiliated outpatient service centers. In addition, it is possible some newer hospitals were not contacted as it was found 2 of the hospitals listed on mnhospitals.org had been closed for greater than 1 year highlighting the possibility of not having been updated within that time. A limitation to this research is the exclusion of outpatient radiology centers. It would be logical to investigate to what extent outpatient radiology centers and mobile MRI units full-fill the disparities revealed by this research in the rural setting. Other future directions include better characterizing the effect the lack of accessibility to an MRI and/or CT machine has on a community’s health, what the ideal square mileage per MRI and CT machine is for a given population and how to make these resources affordable in the rural setting. Although these questions have yet to be answered, this research has reached a conclusion with reasonable certainty. When comparing counties of Minnesota by their RUCA classifications, a disparity is found in rural counties with regards to square mileage per CT and MRI machine. With the primary root of these accessibility issues residing in distance for service, patients would benefit from more rural county in-hospital MRI and CT machines. With these findings, it is pertinent further research is conducted to investigate the potential vulnerability of other rural populations with regards to accessibility to radiologic resources.

Correspondence: Benjamin Burdorf, Northeast Ohio Medical University, Rootstown, Ohio 44272, USA. E-mail: bburdorf@neomed.edu

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