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Download date / Datum preuzimanja: **2025-03-29**

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Geographical and Temporal Distribution of Radiologists, Computed Tomography and Magnetic Resonance Scanners in Croatia

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Abstract

The aim of the study was to analyse the temporal and geographic distribution of radiologists, computed tomography and magnetic resonance scanners in Croatia. In this observational study we estimated radiologists' number per 100,000 population for 1997, 2006, and 2017 and compared private and public CT and MR scanners between 2011 and 2018. We analyzed the availability of radiologists and scanners, and the relationship between the radiological workforce and economic strength among counties. The workforce increased significantly from 1997 to 2017 and was associated with economic strength categories in 2017. In 2018, there were more CT scanners in the public sector, while MR scanners were distributed evenly. In 2011, there was similar distribution of CT and MR between sectors, while in 2018 there were significantly more public CT scanners. Counties with a medical school had significantly more radiologists and MR scanners. The high-to-low ratios per CT and MR were 11 and 8.2, suggesting inequality of health care. Croatia significantly increased its radiological workforce; however, cross-county inequality remained. Counties with higher economic strength and medical schools have better availability of radiologists and equipment. To ensure the sustainable activity of the health care system, a precise estimate of supply and demand of radiology services is needed.

Keywords

radiologists, workforce, Croatia, radiologist rate, CT/MR scanners

What Do We Already Know About This Topic?

Increased utilization of radiology services and the shortage of the radiologists with consequently prolonged waiting times and distribution gaps of radiology resources are negatively affecting health services worldwide.

How Does Your Research Contribute to the Field?

The article quantifies the distribution gaps of the main radiology resources (workforce and equipment) at the national level and provides the inequality level of the radiology services availability, thus offering the analysis and solution framework for further national and regional health care organization research.

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What are Your Research's Implications Towards Theory, Practice, or Policy?

The results of the article are applicable in the national and regional capacity planning policies regarding human and technical radiology resources by taking into account seasonal demands and variations, and furthermore are offering a framework for future assessment of responsible utilization of radiology services and its impact on waiting time.

Introduction

Radiological technical advances are rapidly contributing to the improvement of standard and novel imaging modalities. High-technology medical equipment, such as computed tomography (CT) and magnetic resonance imaging (MRI) scanners are fundamental in the majority of diagnostic and follow-up algorithms, and a necessity within the health care system. Increased utilization placed radiology services under pressure to maintain quality and efficiency, which requires strategic planning of human and technology resources.[1] Increased demand for radiology services and the shortage of radiologists is affecting health services worldwide. Radiology services are greatly influenced by the supply and demand oscillations—supply is influenced by the number of trained radiologists while demand is determined by demographics and technological innovation.[2] The number of radiologists per 100,000 general population, a quantitative workforce indicator, greatly varies within Europe.[3] Great Britain has by far the lowest number of radiologists per capita (4.9/100,000), whereas Greece has an exceptionally high density (31/100,000). Croatia has 10.9 radiologists per 100,000 general population, while other transitional countries, such as Slovenia, Bulgaria, Estonia, and Lithuania, have 13 to 21, while Poland and Romania have 10.[4] In some countries policy instruments in supply and demand sides are needed to manage medical technology diffusion.[5] The numbers of radiology equipment are often presented at national level while in-depth analyses of distribution are still limited.[6,7,8] Internationally observed growth and overutilization of diagnostic imaging further increased awareness of gaps in the distribution of radiology resources as a parameter of health care quality.[9] To diminish such gaps, radiology workforce should be adequately educated and high cost radiology equipment optimally implemented according to local needs. In Croatia, the higher density of radiology workforce and technology in large cities can be explained by combination of their geographical and administrative position within medical and education system. The migration of radiologists toward large cities with medical schools can be explained with their concerns about their professional life (e.g., opportunities for career development, income, working hours) and social opportunities. Studies of optimal technology and workforce distribution may serve as foundation for subsequent analyses and outcome-oriented decisions for policy makers but their availability is limited.

This is the first study which analyze the temporal and geographical distribution of the radiologist workforce, as well as of CT and MRI scanners in Croatia.

Materials and Methods

This study did not involve human subjects and does not require institutional review board approval.

The absolute numbers of radiologists were obtained from the Croatian Institute of Public Health for years 1997, 2006, and 2017.[10] In this observational study conducted in 2019 we estimated the national and county rates of radiologists for the years 1997, 2006, and 2017. The nominator was the number of radiologists for these years while denominator was the number of general population at national and county level according to the nearest population censuses from 1991, 2001, and 2011 and it was expressed per 100,000.[11]

The Croatian Ministry of Health provided the national number of CT and MR scanners in the private and public sector for 2011 and 2018; availability was compared for the aforementioned years. For 2018, data were also available at the county level, thus we estimated the availability of CT and MR scanners per capita on this level as well.

The rates of radiologists, MR, and CT scanners were compared between two county groups; those with medical schools (City of Zagreb, Primorje-Gorski Kotar County, Osijek-Baranja County and Split-Dalmatia County) and counties without medical school. Additionally, we compared values of these rates at county level with average values at national level.

We estimated the association between the radiological workforce and economic strength expressed as the Croatian Chamber of Economy (CCE) index for 2017.[12] This composite index represents the sum of the weighted ranks of GDP per capita, entrepreneurs' total revenues per employee, entrepreneur's revenue on foreign markets per employee, entrepreneurs net profit per employee, average net salary, unemployment rate, and projections of population growth 2013–2030. Counties were divided into low (67.7–77.3), lower-intermediate (77.6–85.8), upper-intermediate (87.1–92.1), and high (95.2–147.6) CCE index categories and higher scores indicate higher economic strength.

Statistical Analysis

The number of radiologists was expressed as rate per 100,000 general population per year. The maximum county-to-county variations were calculated per year as the ratio between the highest and lowest radiologist rates. Percentage changes (PC) for every county were measured by comparing radiologist rates
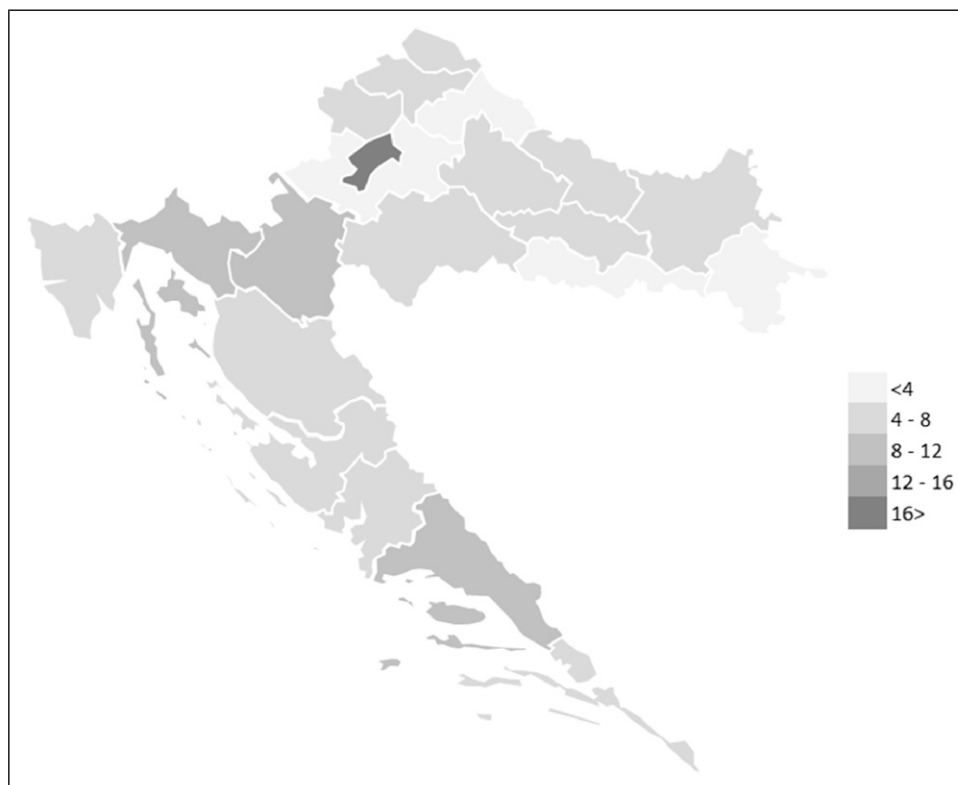
Figure 1. The number of radiologists per 100,000 general population in 1997.

from 1997 to 2017. We tested the normality of the data with Shapiro–Wilk test. To determine if there is a statistically significant difference between individual county's and the national rate of radiologists, non-parametric one sample Wilcoxon signed rank test was conducted. Differences between number of CT/MR scanners per each county and national average were tested with one sample t-test. To test if there is a statistically significant difference in the number of CT scanners per 100,000 between counties with a medical school and the ones without it, we conducted independent samples t-test. Difference in average number of MR scanners per 100,000 between counties with a medical school and the ones without it, was tested with non-parametric Mann–Whitney test. The χ^2 test was used to evaluate differences in frequencies of categorical variables. The level of significance was $P < .05$. Analyses were performed using the SPSS version 27.

Results

The absolute number of radiologists at national level increased from 336 in 1997 to 360 in 2006, and 475 in 2017. The number of radiologists per 100,000 increased from 5.9 in 1997 (Figure 1) to 6.3 in 2006 (Figure 2), and 9.0 in 2017 (Figure 3). The increase was significant from 1997 to 2017 ($P = .028$). The rate of radiologists was not normally distributed across counties (Table 1).

The City of Zagreb had the highest number of radiologists per 100,000 general population in all analyzed years. The high-to-low ratios were 6.3 in 1997, 6.6 in 2006, and 6.8 in 2017. The number of counties with significantly higher number of radiologists per 100,000 general population compared with national median has changed in analyzed years. There were five counties in 1997, six in 2006, and seven in 2017, while the number of counties with significantly lower rate was eight in 1997, seven in 2006, and seven in 2017, respectively. Only three counties had in all aforementioned years significantly higher rate of radiologists compared with national median-City of Zagreb, Karlovac and Primorje-Gorski Kotare, and also three counties had significantly lower rates for those years-Vukovar-Srijem, Virovitica-Podravina and Zagreb (Table 1).

In 2017, the radiologist workforce was significantly associated with CCE index according to county categories ($P = .020$). Figure 4 Counties with a medical school had significantly more radiologists ($P = .009$).

Percentage change of radiologists per 100,000 general population from 1997 to 2017 increased in 18 counties from 10.1% in Virovitica-Podravina county to 234.4% in Brod-Posavina county, while the radiology workforce decreased in Lika-Senj (−29.7%), Sisak-Moslavina (−3.2%) and Bjelovar-Bilogora (−7.4%) counties (Figure 5).
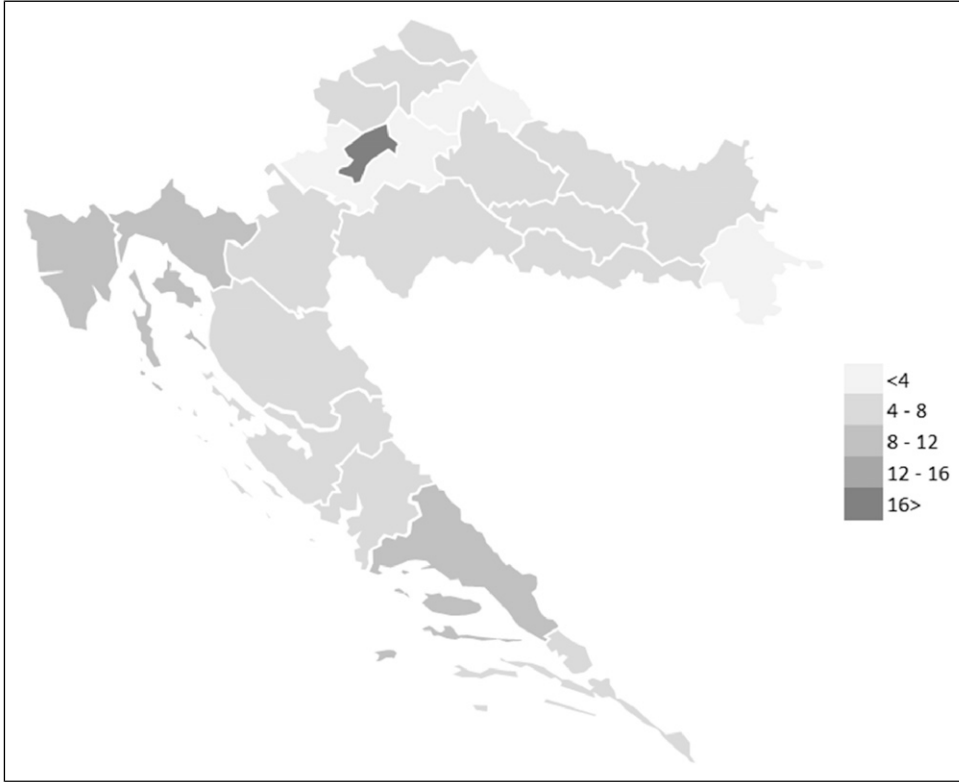
Figure 2. The number of radiologists per 100,000 general population in 2006.
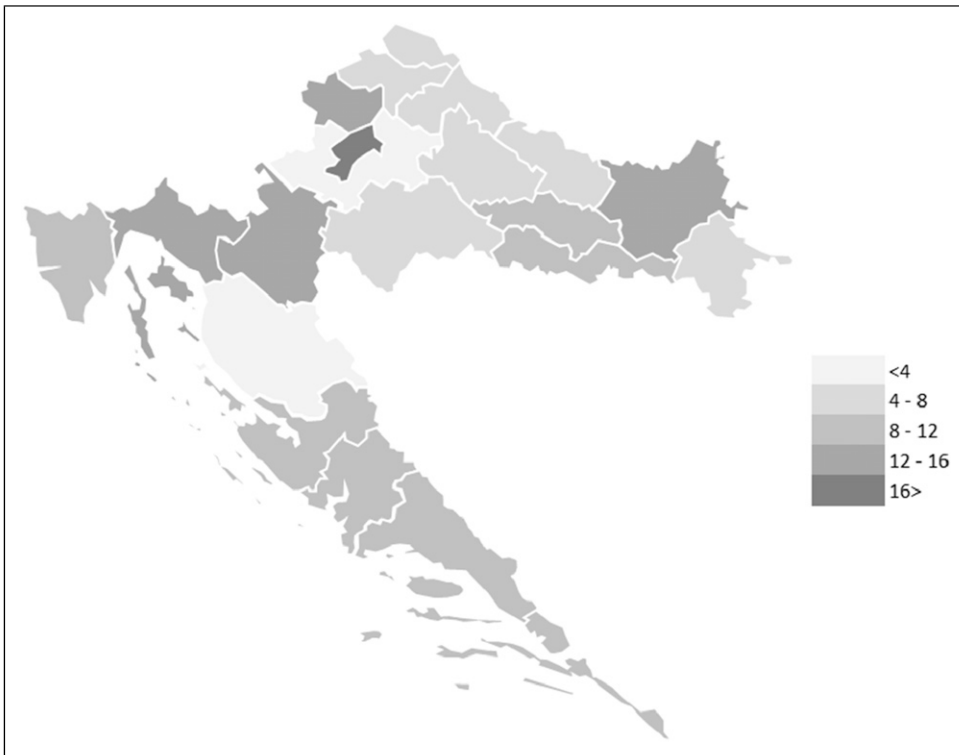
Figure 3. The number of radiologists per 100,000 general population in 2017.

Table 1. The Number of Radiologists per 100,000 General Population (County vs National Level) and CCE Indices.

	1997	County vs national median 1997	2006	County vs national median 2006	2017	County vs national median 2017	CCE index 2017
National median	5.4	P	5.6	P	9.1	P	85.8
City of Zagreb	16.3	.000	17.2	.000	21.4	.000	147.6
Osijek-Baranja	6.3	.149	7.3	.025	13.7	.001	80.9
Krapina-Zagorje	4.9	.217	7.0	.068	12.8	.001	87.1
Karlovac	8.5	.001	7.8	.008	12.4	.003	85.8
Primorje-Gorski Kotar	9.5	.001	9.8	.001	12.1	.005	105.5
Požega-Slavonia	5.8	.498	5.8	.917	11.5	.012	67.9
Brod-Posavina	3.4	.000	5.1	.122	11.3	.016	71.6
Dubrovnik-Neretva	6.5	.063	4.9	.033	9.8	.217	92.1
Istria	6.8	.030	8.7	.002	9.6	.339	127.3
Split-Dalmatia	8.2	.002	8.6	.002	9.5	.394	80.8
Šibenik-Knin	6.2	.218	6.2	.588	9.1	.664	77.6
Zadar	4.9	.217	5.5	.414	8.2	.455	91.3
Koprivnica-Križevci	3.2	.000	3.2	.000	7.8	.259	90.7
Varaždin	4.3	.012	4.3	.002	7.4	.126	99.6
Međimurje	4.2	.006	5.1	.122	7.0	.046	91.0
Sisak-Moslavina	5.4	.903	4.3	.002	5.2	.001	79.7
Vukovar-Srijem	2.9	.000	3.9	.000	5.0	.001	77.3
Virovitica-Podravina	4.3	.012	4.3	.002	4.7	.000	67.7
Bjelovar-Bilogora	4.5	.035	6.0	.848	4.2	.000	68.0
Lika-Senj	5.6	.768	5.6	.566	3.9	.000	76.0
Zagreb	2.6	.000	2.6	.000	3.1	.000	95.2

Density of CT and MR Scanners

In 2011 there were 16 private (0.4 per 100,000) and 50 public (1.2 per 100,000) CT scanners while in 2018 there were 77 scanners, 60 public (1.4 per 100,000) and 17 private (0.4 per 100,000) (Figure 6).

In 2011 there were 14 private (0.3 per 100,000) and 25 public (0.6 per 100,000) MR scanners while in 2018 there were 25 private (0.6 per 100,000) and 26 public (0.6 per 100,000) scanners (Figure 7). The distribution of private and public CT and MR scanners was similar in 2011, while there were significantly more public CT scanners in 2018 ($P = .001$).

The average number of CT and MR per 100,000 general population was 1.6 and 1.0, respectively.

Counties with medical schools had significantly more MR scanners ($P = .031$), as opposed to the more equal distribution of CT scanners between these groups ($P = .188$). Among counties with medical schools, two had significantly higher and one significantly lower CT rates than the national mean. MR rates higher than the national mean were observed in all four counties with medical schools, but were significantly higher in two counties. (Table 2)

In the group of counties without medical schools, CT rates were significantly higher than the national mean in five and significantly lower in eight counties. Three counties in this group had significantly higher and five significantly lower MR rates than the national mean (Table 2).

The high-to-low ratios per CT and MR were 11.0 and 8.2, respectively.

Discussion

This is the first study of the temporal and geographical distribution of radiologists and high-technology equipment in Croatia. The number of radiologists per 100,000 general population varies among European countries. In Croatia, the number of radiologists per 100,000 increased from 5.9 in 1997 (Figure 1) to 6.3 in 2006 (Figure 2), and 9.0 in 2017 (Figure 3). Although radiological workforce significantly increased from 1997 to 2017, it remained below the European average of 12.7/100,000.[13]

Croatia should not face capacity challenges with such overall radiological workforce; however, a cross-county comparison revealed pronounced differences. As many as 18 counties increased their radiologist-to-general-population supply; however, high geographic and long-standing temporal variations remained within entire study period (Figures 1-3). Workforce inequalities, expressed as high-to-low ratio, increased by 7.6% from 1997 to 2017. This uneven geographical distribution could be obstacle to the country-wide provision of radiological services, especially in small
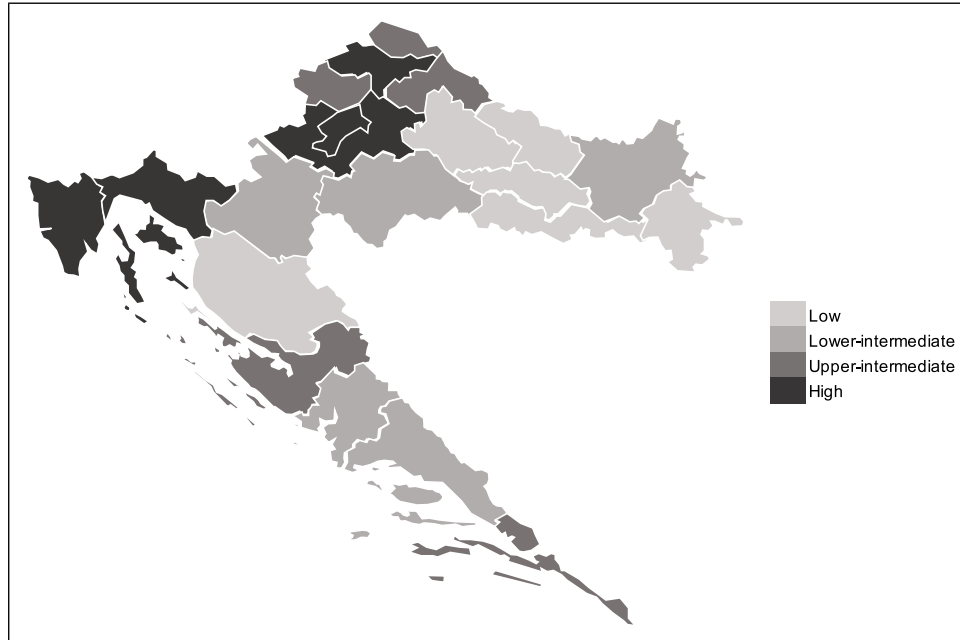
Figure 4. Distribution of Croatian Chamber of economy indices for 2017. Across counties; low (67.0–77.3), lower-intermediate (77.6–85.8), upper-intermediate (87.1–92.1), high (95.2–147.6).
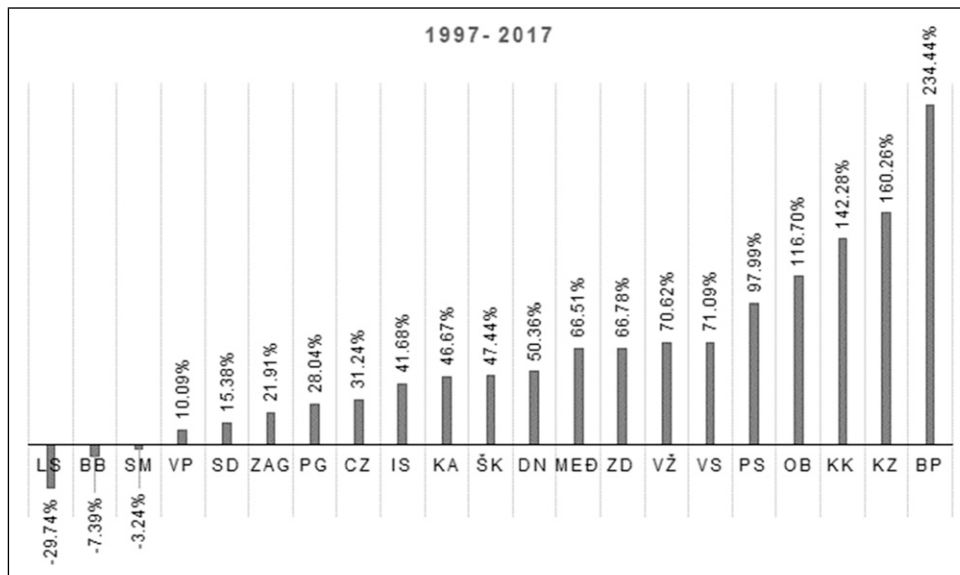

Figure 5. Percent change in radiologists per 100,000 general population from 1997 to 2017. LS, Lika-Senj; BB, Bjelovar-Bilogora; SM, Sisak-Moslavina; VP, Virovitica-Podravina; SD, Split-Dalmatia; ZAG, Zagreb; PG, Primorje-Gorski Kotar; CZ, City of Zagreb; IS, Istria; KA, Karlovac; ŠK, Šibenik-Knin; DN, Dubrovnik-Neretva; MEĐ, Međimurje; ZD, Zadar; VŽ, Varaždin; VS, Vukovar-Srijem; PS, Požega-Slavonia; OB, Osijek-Baranja; KK, Koprivnica-Križevci; KZ, Krapina-Zagorje; BP, Brod-Posavina.

counties. Contrary to the unfavorable position of smaller counties, the availability of radiologists in large counties with medical schools is significantly higher. Large teaching hospital centers are investing into radiological workforce and equipment, thus further widening the gap.

European radiology has been affected by the economic crisis in numerous aspects.[14] Among transitional countries, Croatia experienced a more severe and longer economic crisis, which led to significant regional disparities.[15] It also has one of the lowest health care expenditure rates in the
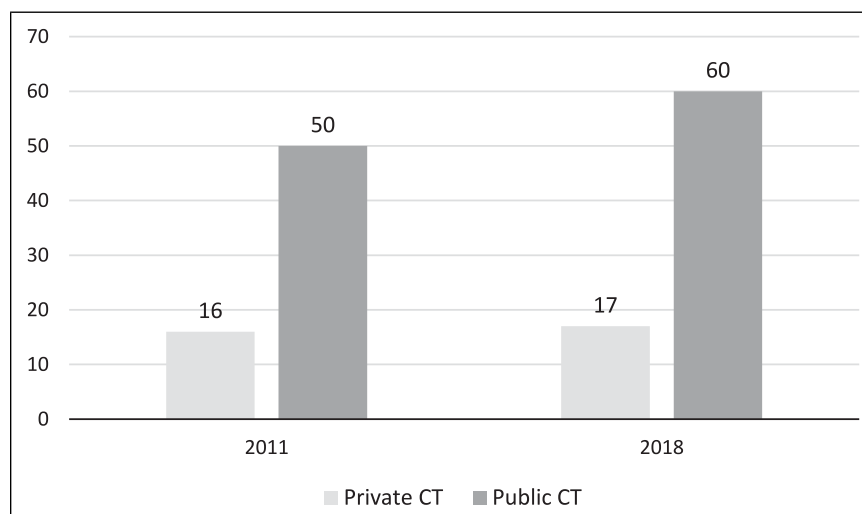
Figure 6. Number of CT scanners.
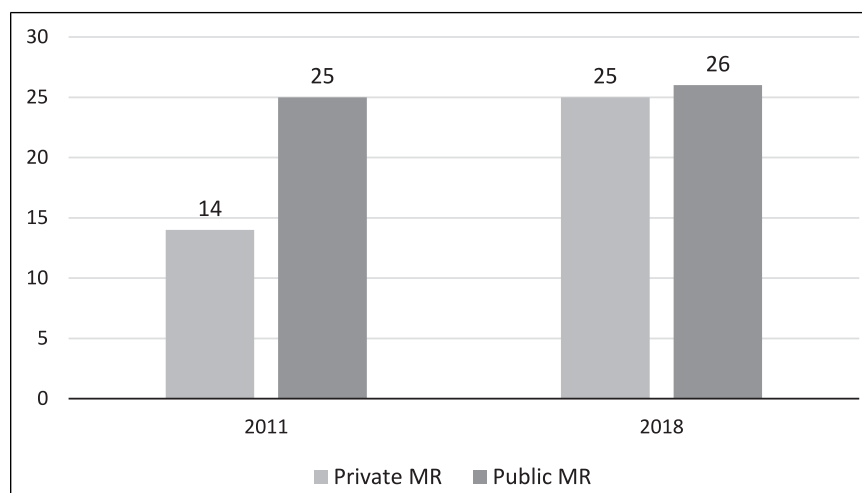
Figure 7. Number of MR scanners.

European Union.[16] Compared with other specialties radiology is technology-driven field that is mostly determined by economic factors. Economically and demographically disadvantaged eastern Croatian counties with a low CCE index also had the lowest radiologist rates. (Figure 4; Table 1) Still, low availability in some counties may not implicate a lack of radiological services and should be explained with caution. Counties with a shortage of radiologists during weekends and vacancies regularly employ consultants, who usually work at multiple public and private sites. This kind of solution temporarily narrows the capacity gap between metropolitan areas and smaller local centers. Moreover, large medical centers may even have longer patient wait times, which are commonly perceived as indicators of quality of care.[17,18] Still, such health care solutions should not become a long-term strategy for the provision of radiology service, as extreme overwork severely decreases radiologists' health and increases risk of burnout.[19] Since consultant radiologists are registered within their primary clinics, the number of such consultations is not yet available. Some changes to optimize radiology service delivery can be easily implemented across all imaging departments without substantial investments in human and technological resources. Stratified measures for reducing long wait times for CT and MR services should include nationally networked schedule adjustment with, if possible, waiting time targets for CT and MR imaging. Permanent review of scanning protocols and the use of clinical criteria for access to radiology services based on patients' medical history would differentiate some categories, such as urgent vs non-urgent, oncologic vs non-oncologic patients and initial vs follow-up imaging, and would reduce

Table 2. The Number of CT and MR Scanners per 100,000 General Populations in 2018 – County (With and Without Medical Schools) and National Level.

Counties without medical school	CT	CT County vs national mean	MR	MR County vs national mean
National mean	1,6	P	1,0	P
Bjelovar-Bilogora	0.8	.000	0.8	.281
Brod-Posavina	1.3	.073	0.6	.029
Dubrovnik-Neretva	2.5	.000	1.6	.001
Istria	1.0	.002	0.5	.008
Karlovac	1.6	.833	0.8	.281
Koprivnica-Križevci	0.9	.001	NA	NA
Krapina-Zagorje	2.3	.001	0.8	.281
Lika-Senj	2.0	.056	2.0	.000
Međimurje	1.8	.375	0.9	.632
Požega-Slavonia	2.6	.000	2.6	.000
Sisak-Moslavina	0.6	.000	NA	NA
Šibenik-Knin	2.7	.000	0.9	.632
Varaždin	1.1	.007	0.6	.029
Virovitica-Podravina	2.4	.000	NA	NA
Vukovar-Srijem	1.1	.007	0.6	.029
Zadar	1.2	.023	1.2	.183
Zagreb	0.3	.000	0.3	.000
Counties with medical school				
City of Zagreb	3.4	.000	2.5	.000
Osijek-Baranja	1.0	.002	1.3	.059
Primorje-Gorski-Kotar	2.4	.000	1.4	.016
Split-Dalmatia	1.8	.375	1.3	.059
Difference between counties with and without medical school	P = .188		P = .031	

NA, not available.

the demand side. A precise analysis of the health system would require the mandatory collection of data on work-flow and radiological services. Since radiological supply/demand data are not available, this workflow represents a real-life manifestation of the capacity challenge.

The lower number of radiologists in some counties can be explained through emigration from Croatia after accession to the European Union.[20] Radiologists are leaving for higher-paying, less stressful jobs and career advancement, while experienced professionals are retiring. We are also witnessing migration towards larger centers for better career opportunities and the implementation of advanced imaging technologies. New technologies are perceived as attractive by both, physicians and patients. The use of medical services in Croatia is not restricted to the place of residence and patients tend to seek radiology services in large tertiary centers. Advances in imaging technology required special education and led to establishment of new subspecialties characterized by the use of image-guided intervention or the combining of two specialties, for example, radiology and cardiology.[21] Novel technologies and sub specialization, increased the number of radiologists in large centers and facilitated migration and staying of graduates in counties with medical schools. Counties without medical schools had to face challenges of new technologies and further increase efforts to ensure the quality of imaging services.

There is also high regional imbalance regarding the distribution of imaging technologies. Nationally, demand for imaging services is increasing, placing a substantial economic burden on the health care system. MR availability shows unequal distribution among counties and high-to-low ratio of 8.2 (Table 2). As expected, large centers with medical schools have better MR availability ($P = .031$), as opposed to Koprivnica-Križevci, Sisak-Moslavina, and Virovitica-Podravina counties, where patient's needs for MR were still unmet in 2018. According to the previous study, health inequalities were more obvious in Croatia than in EU countries; citizens also perceived the distance to the nearest medical facility as a very serious problem.[22] Over the past decade the growth opportunities in the radiology service market were mostly driven by the technology advances and increased awareness. The private sector has recognized that demand for MR services exceeded supply, and filled the gap in this product area.[23] In 2011–2018 period the number of

MR scanners increased by 30%, with the contribution of private sector of 78.5%. (Figures 6 and 7). The majority of the private health market is financed with out-of-pocket money which increases the risk from over-diagnosis and over-treatment. Occasionally, some private health care services are reimbursed by the mandatory national insurance fund. Therefore, public and private radiological services cannot be easily distinguished on the radiology market, and data referring to these two health care systems should be interpreted with caution. MR per capita in the capital of Zagreb is similar to that of high-income EU countries, such as Italy and Germany, and is above OECD average for 2016 (1.6). Croatia has a higher average MR rate (1.2) than Hungary (0.4), the Czech Republic (0.8), and Slovenia (1.1), but lower than Austria (2.2) and Italy (2.8).

CT high-to-low ratio of 11.0 is higher than for MR. The availability of CT per capita of 1.6 is much higher than Hungary (0.9), similar to Slovenia (1.4) and the Czech Republic (1.5), and much lower than Austria (2.9) and Italy (3.4).[24] In 2011, the distribution of CT and MR scanners between private and public sectors was similar, while the public sector had significantly more CT scanners in 2018. The number of CT scanners increased by 16.6%, and as opposed to MR, the private sector participated with only 9.1%. Optimization of medical imaging service equity at national level could be facilitated through implementation of the OECD general guideline in the density of CT and MR scanners.[25] Equilibrium between demand and supply can be more easily reached with the adoption of evidence-based medicine in radiology practice since it would reduce unnecessary utilization and/or overuse of radiological equipment. It would also raise awareness of patient's radiation burden which requests continuous auditing of radiological investigations.

Geographic misdistributions of radiologists in Croatia cannot be addressed by simply increasing their overall number. To maintain sufficient level of health care, future needs for radiological services must be planned at the regional level. As many other countries Croatia is facing an ever-increasing demand for imaging services as a consequence of technological progress, broader clinical indications, defensive medical practices, and population aging.[26] The density of CT and MR scanners in the future should consider changes in population structure. UN demographic projections suggest possible decline of Croatian population by more than 17% between 2017 and 2050.[27] Population aging and the burden of disease demand more precise analysis, especially regarding the need for subspecialties in neuroradiology and musculoskeletal radiology.[28] Consequently, coordinated workforce plans that include information-based predictions of future radiology workforce are desired. Education of referring physicians about guidelines accordant indications is difficult, but perhaps the most important task for radiologists. Therefore, identifying demand in the use of radiology services in the future may be of special interest, and should facilitate health policy planning.

Limitations

Our study has some limitations. First, the number of radiologists was available only for three years; a larger dataset would have allowed a more precise analysis. Second, the distribution of radiologists and imaging equipment should be perceived only as an estimate of radiological services. The average workload per radiologist still remains unknown; there is no reliable means by which to estimate the total use of imaging nationally. Third, cross-county imbalances are partly justified. County-level data were analyzed; however, the use of regional health care services is not mandatory and patients are given direct access to tertiary, university-affiliated institutions. CT and MR are complex, labor-intensive, and time-consuming examinations to interpret and report, which justifies investment into workforce and imaging equipment in large centers. The number of trained radiologists available to analyze these images is more accurate indicator but beyond the scope of this study.

Conclusion

Large gaps still exist in the distribution of CT and MRI scanners. Although within the past two decades, Croatia has significantly increased its radiological workforce, cross-county variances remain. Moreover, counties with higher economic strength and medical schools have higher density of radiologists and imaging equipment. Efficient strategies at the local and national level are needed to reach supply/demand equilibrium to ensure the optimization of radiology services and sustainable health care system.

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