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RESEARCH ARTICLE

Rural-Urban mild cognitive impairment comparison in West Michigan through EHR

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Abstract

INTRODUCTION: Mild cognitive impairment (MCI) is a significant public health concern and a potential precursor to Alzheimer's disease (AD). This study leverages electronic health record (EHR) data to explore rural-urban differences in MCI incidence, risk factors, and healthcare navigation in West Michigan.

METHODS: Analysis was conducted on 1,528,464 patients from Corewell Health West, using face-to-face encounters between 1/1/2015 and 7/31/2022. MCI cases were identified using International Classification of Diseases (ICD) codes, focusing on patients aged 45+ without prior MCI, dementia, or AD diagnoses. Incidence rates, cumulative incidences, primary care physicians (PCPs), and neuropsychology referral outcomes were examined across rural and urban areas. Risk factors were evaluated through univariate and multivariate Cox regression analyses. The geographic distribution of patient counts, hospital locations, and neurology department referrals were examined.

RESULTS: Among 423,592 patients, a higher MCI incidence rate was observed in urban settings compared to rural settings (3.83 vs. 3.22 per 1,000 person-years). How-

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ever, sensitivity analysis revealed higher incidence rates in rural areas when including patients who progressed directly to dementia. Urban patients demonstrated higher rates of referrals to and completion of neurological services. While the risk factors for MCI were largely similar across urban and rural populations, urban-specific factors for incident MCI are hearing loss, inflammatory bowel disease, obstructive sleep apnea, insomnia, being African American, and being underweight. Common risk factors include diabetes, intracranial injury, cerebrovascular disease, coronary artery disease, stroke, Parkinson's disease, epilepsy, chronic obstructive pulmonary disease, depression, and increased age. Lower risk was associated with being female, having a higher body mass index, and having a higher diastolic blood pressure.

DISCUSSION: This study highlights rural-urban differences in MCI incidence and access to care, suggesting potential underdiagnosis in rural areas likely due to reduced access to specialists. Future research should explore socioeconomic, environmental, and lifestyle determinants of MCI to refine prevention and management strategies across geographic settings.

KEYWORDS
dementia, electronic health records, health disparity, incidence rates, mild cognitive impairment, risk factors, urbanization

Highlights

- Leveraged EHRs to explore rural-urban differences in MCI in West Michigan.
- Revealed a significant underdiagnosis of MCI, especially in rural areas.
- Observed lower rates of neurological referrals and completions for rural patients.
- Identified risk factors specific to rural and urban populations.

1 | BACKGROUND

Mild cognitive impairment (MCI) is an intermediate stage between normal cognitive aging and dementia characterized by a noticeable decline in cognitive abilities beyond typical age-related changes.[1] With the American population aged 65+ projected to reach 98 million by 2060,[2] understanding MCI prevalence becomes crucial. A recent study estimated the prevalence of MCI in people aged 65+ to be 22%.[3] Notably, 10-15% of MCI individuals progress to dementia annually,[4] with one-third developing Alzheimer's disease (AD) within 5 years.[5] Early identification and intervention for MCI can potentially reverse or delay progression through strategies to address modifiable risk factors, including cognitive training, dietary changes, physical exercise, and therapeutics such as Lecanemab and Donanemab.[6,7] A meta-analysis showing that 18% of MCI patients may revert to normal cognition.[8]

Emerging literature highlights the importance of geographical settings, particularly rural and urban environments, on MCI risk factors.[9–11] Although prior studies have explored rural-urban differences in MCI prevalence and risk factors in the elderly in Asian countries,[12–16] studies within the United States (US), especially targeting middle-aged populations, remain sparse. Existing studies in the US have shown rural-urban variations in MCI symptom severity and diagnosis intervals, as well as the prevalence of dementia and cognitive impairment.[17–19] These studies broaden the understanding of variations in cognitive health. However, further investigation into geographical differences is still needed, particularly in MCI incidence and risk factors.

Cohort studies, designed for research with regular, direct assessments, typically report higher MCI incidence rates than those derived from electronic health records (EHRs). The MCI incidence rates in individuals aged 65+ range from 21.5 to 71.3 per 1,000 person-years in a systematic review.[20] In contrast, EHR-based studies often present a different perspective on the incidence of cognitive disorders, capturing the intricacies of clinical practice where diagnoses result from symptomatic presentation and the insights of healthcare providers. For instance, a nationwide study in Israel utilizing International Classification of Disease (ICD) codes identified dementia incidence rates of 0.36% among individuals aged 45+ and 0.96% among those aged 65+.[21] Another study highlighting the positive predictive value of dementia diagnoses in EHRs reported age and sex-standardized incidence rates of 8.6 per 1,000 person-years.[22] Moreover, researchers found that the incidence of dementia was 1.88 per 1,000 person-years at risk for individuals aged 60-79 years, and 16.53 per 1,000 person-years at risk for those aged 80-95 years.[23] This discrepancy

underscores the necessity of interpreting the EHR-based findings with an understanding of the inherent limitations and methodological differences compared to traditional cohort studies.

Michigan has a substantial aging population, with the number of AD cases projected as 220,000 by 2025.[24] Furthermore, previous studies suggested that subjective cognitive decline (SCD) was associated with an increased risk of incident MCI,[25] and Michigan already exhibits a relatively high prevalence of SCD among individuals aged 45+.[26] The diverse geographic densities and landscapes of West Michigan provide a unique context to investigate the rural-urban incident MCI. This study is the first to leverage high-volume, comprehensive EHR data to examine MCI incidence and healthcare navigation discrepancies in Michigan's rural and urban populations. By investigating visits to primary care physicians (PCPs), neuropsychology referrals, and the progression from MCI to dementia, our research shows rural-urban differences and calls for targeted public health initiatives and interventions to alleviate the MCI burden.

RESEARCH IN CONTEXT

1. **Systematic review**: We conducted a thorough literature review using databases such as ScienceDirect, PubMed, and Springer. We focused on studies related to mild cognitive impairment (MCI) incidence and risk factors, with a particular interest in differences between rural and urban populations. While previous research has explored geographic differences in incident MCI, limited studies have utilized electronic health records (EHRs) to compare geographic settings within the United States.
2. **Interpretation**: Our study fills this gap by identifying significant rural-urban differences in MCI incidence and healthcare access within West Michigan, uncovering likely underdiagnosis in rural areas alongside unique urban risk factors. Our research suggests systemic barriers in rural neurological service access and highlights the need for targeted public health initiatives and interventions to mitigate these differences. Tailored strategies are needed to enhance MCI detection, management, and equitable healthcare delivery.
3. **Future directions**: Future studies should explore the complex interplay of socioeconomic, environmental, and lifestyle determinants of MCI risk across geographies.

2 | METHODS

2.1 | Study design

This study was approved by the Institutional Review Board (IRB) at Michigan State University (MSU) and Corewell Health West (CHW). CHW's EHR contains data from facilities in West Michigan. 1,528,464 patients were identified in the CHW Epic database with face-to-face encounters 1/1/2015-7/31/2022. These encounters include emergency, inpatient, and outpatient settings. The first encounter after 1/1/2015 was designated as the baseline visit. While primarily West Michigan patients, our study included patients from other Michigan regions who received care at CHW. Inclusion criteria were as follows at baseline: (1) aged 45+; (2) having at least one subsequent face-to-face clinical encounter postbaseline; (3) without a documented MCI, dementia, or AD; (4) without brain cancer; and (5) with completed demographics and Michigan residency. Patients who progressed to dementia or AD directly from a cognitively unimpaired (CU) state, bypassing an intermediate MCI diagnosis, were excluded from the primary analysis while included in the subsequent extended sensitivity analysis. The 45+ age threshold for inclusion aligns with observed trends in preliminary data suggesting increasing MCI diagnosis beginning at this age (Figure S1). The study flowchart is shown in Figure 1.

Baseline residency classification utilized Rural-Urban Commuting Area (RUCA) codes,[27] specifically employing Category C definitions from the University of Washington's Rural Health Research Centre (Table S1). Corewell Health's hospital facilities are widely distributed across West Michigan, spanning both urban and rural areas as defined by RUCA codes. Consequently, the data in our study offer a comprehensive representation of a diverse population from multiple counties with a balanced insight into healthcare dynamics across different geographic settings.

2.2 | Measurements

MCI cases were identified using the International Classification of Diseases, Ninth Revision (ICD-9 code = "331.83") and Tenth Revision (ICD-10 code = "G31.84"). We then identified twenty-eight potential risk factors based predominantly upon association with incident MCI in CHW's EHR, supported by previous studies. These factors span demographics, vitals, and comorbidities as detailed in Table S2. All factors were assessed at the baseline visit unless specified otherwise.

2.3 | Statistical analysis

We conducted comparative analyses between rural and urban populations. To address missing data, predictive mean matching[28] was used for multiple imputation. Detailed statistical methods, including calculations of MCI incidence rates and patient navigation analyses, are provided in Supplementary Text.

2.4 | Sensitivity analyses

Sensitivity analyses included a robust dual approach. First, we conducted a complete-case assessment to assess the impact of missing data imputation. Second, we performed an extended analysis with

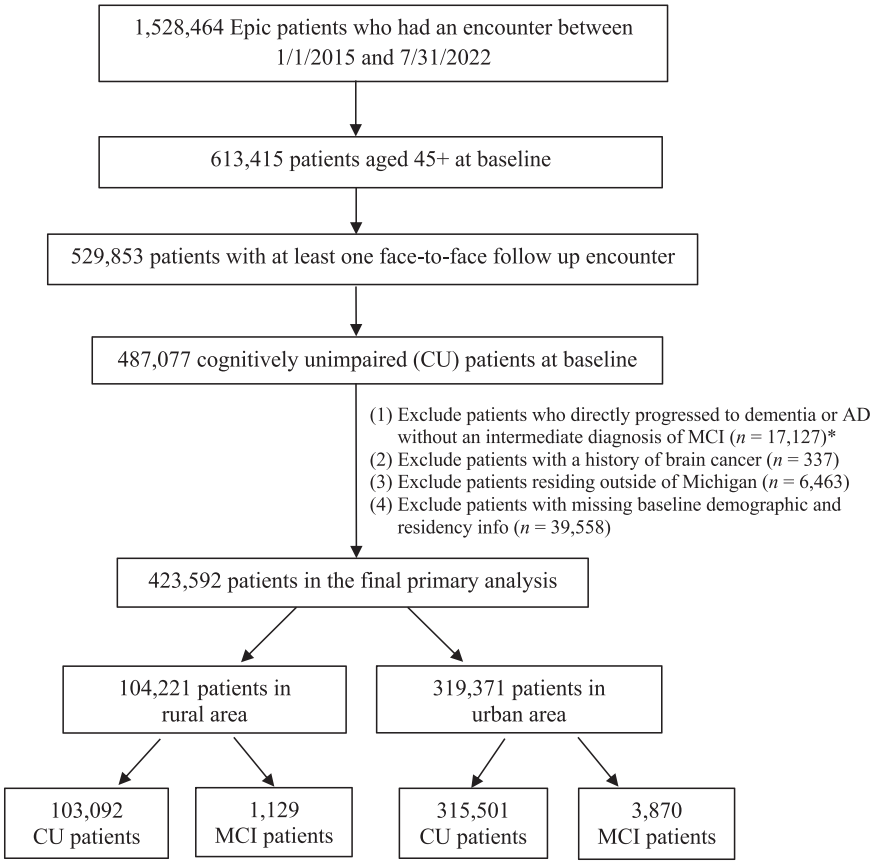

FIGURE 1 Flowchart of the study in the primary analysis.

broader inclusion criteria, including patients who progressed directly to dementia or AD without an intermediate MCI diagnosis ("MCI skippers"). This analysis assumes that all dementia patients first had MCI and estimates MCI onset as the midpoint between initial encounter and dementia diagnosis.

3 | RESULTS

3.1 | Characteristics of study patients

Among 423,592 patients included, 24.6% (104,221) resided in rural areas, while 75.4% (319,371) lived in urban areas (Table 1). RUCA-based categorization of patient residences remained stable, with only 1.4% of patients changing categories during follow-up. Both RUCA categorizations and cognitive classifications are visually presented in Figure S2. Within demographics, several differences were identified across rural and urban populations. Age distribution and median age were marginally higher in rural populations, with fewer individuals aged 45-54. The rural population had a slightly higher male proportion (47.6%) relative to their urban counterparts (46.7%). Racial distribution revealed a larger percentage of African Americans in urban areas (5.6%) compared to rural (1.0%). Within comorbidities, no significant differences between rural and urban populations were found in diabetes, heart disease, intracranial injury, cerebrovascular disease, coronary artery disease (CAD), stroke, and epilepsy. However, differences were observed in the remaining factors, with rural regions generally exhibiting lower rates of comorbidity. Exceptions were the higher rate of obesity (44.7% rural vs. 42.6% urban), vitamin B12 deficiency (0.4% rural vs. 0.3% urban), and chronic obstructive pulmonary disease (COPD) (6.9% rural vs. 4.8% urban) in rural areas.

3.2 | Incidence rate and cumulative incidence of MCI

Out of the total cohort, 1,129 rural patients (1.08%) and 3,870 urban patients (1.21%) were diagnosed with MCI (Table 2). The resulting overall MCI incidence was 3.67 per 1,000 person-years (95% confidence interval [CI], 3.57-3.77) over a median observation period of 3.78 years (range: 7.48 years). The incidence was lower in rural areas at 3.22 per 1,000 person-years (95% CI, 3.04-3.42) and higher in urban areas at 3.83 (95% CI, 3.71-3.95), with the difference being statistically significant ($p < 0.05$). Across geographies, gender, age, and certain demographics revealed clear patterns. Males showed a marginally higher cumulative incidence (1.21%) than females (1.15%).

TABLE 1 Baseline characteristics of patients by residential areas[a].

Characteristic	Overall	Rural	Urban	*p*-value
Total no. patients	423,592	104,221 (24.7)	319,371 (75.3)	
Encounters, mean (SD)	48.1 (67.7)	55.9 (74.2)	45.5 (65.2)	<0.001
Sex				
Male	198,674 (46.9)	49,629(47.6)	149,045 (46.7)	<0.001
Female	224,918 (53.1)	54,592 (52.4)	170,326 (53.3)	
Age, years, median (IQR)	61.0 (16.0)	62.0 (16.0)	61.0 (16.0)	<0.001
Age group (years)				
45-54	120,000 (28.3)	26,887 (25.8)	93,113 (29.2)	<0.001
55-64	139,523 (32.9)	34,559 (33.2)	104,964 (32.9)	
65-74	102,218 (24.1)	26,907 (25.8)	75,311 (23.6)	
75+	61,851 (14.6)	15,868 (15.2)	45,983 (14.4)	
Ethnicity				
Hispanic	3,840 (0.9)	858 (0.8)	2,982 (0.9)	0.001
Race				
White	402,931 (95.1)	102,537 (98.4)	300,394 (94.1)	<0.001
African American	18,770 (4.4)	1,043 (1.0)	17,727 (5.6)	
Other	1,891 (0.4)	641 (0.6)	1,250 (0.4)	
Diabetes	46,549 (11.0)	11,375 (10.9)	35,174 (11.0)	0.38
Hearing loss	21,234 (5.0)	2,792 (2.7)	18,442 (5.8)	<0.001
Heart disease	12,666 (3.0)	3,039 (2.9)	9,627 (3.0)	0.11
Hyperlipidemia	120,951 (28.6)	25,365 (24.3)	95,586 (29.9)	<0.001
Intracranial injury	1,440 (0.3)	350 (0.3)	1,090 (0.3)	0.82
Cerebrovascular	18,638 (4.4)	4,592 (4.4)	14,046 (4.4)	0.92
CKD	17,939 (4.2)	3,494 (3.4)	14,445 (4.5)	<0.001
AFib	23,272 (5.5)	4,933 (4.7)	18,339 (5.7)	<0.001
CAD	37,750 (8.9)	9,158 (8.8)	28,592 (9.0)	0.11
Stroke	14,447 (3.4)	3,629 (3.5)	10,818 (3.4)	0.15
Cancer	57,572 (13.6)	12,036 (11.5)	45,536 (14.3)	<0.001
Parkinson's disease	1,529 (0.4)	325 (0.3)	1,204 (0.4)	0.003
IBD	14,498 (3.4)	2,736 (2.6)	11,762 (3.7)	<0.001
Hyperthyroidism	3,973 (0.9)	700 (0.7)	3,273 (1.0)	<0.001
TIA	6,673 (1.6)	1,543 (1.5)	5,130 (1.6)	0.005
Epilepsy	4,121 (1.0)	1,027 (1.0)	3,094 (1.0)	0.65
VB12 deficiency	1,252 (0.3)	429 (0.4)	823 (0.3)	<0.001
OSA	42,717 (10.1)	8,419 (8.1)	34,298 (10.7)	<0.001
Insomnia	31,075 (7.3)	5,149 (4.9)	25,926 (8.1)	<0.001
COPD	22,502 (5.3)	7,206 (6.9)	15,296 (4.8)	<0.001
Depression	49,104 (11.6)	9,645 (9.3)	39,459 (12.4)	<0.001
BMI, mean (SD)	29.6 (5.86)	29.9 (6.02)	29.5 (5.81)	<0.001
BMI group[b,c]				
Normal weight	59,307 (21.3)	12,151 (19.9)	47,156 (21.7)	<0.001
Underweight	2,939 (1.1)	813 (1.3)	2,126 (1.0)	
Overweight	95,423 (34.3)	19,823 (32.5)	75,600 (34.8)	
Obese	120,795 (43.4)	28,221 (46.3)	92,574 (42.6)	

(Continues)

TABLE 1 (Continued)

Characteristic	Overall	Rural	Urban	*p*-value
DBP, mean (SD), mmHg	76.4 (9.32)	76.4 (9.22)	76.5 (9.35)	0.13
DBP group[b,c]				
Normal	187,516 (61.1)	48,166 (60.9)	139,350 (61.2)	0.05
Prehypertension	94,995 (31.0)	24,742 (31.3)	70,253 (30.9)	
Hypertension	24,204 (7.9)	6,156 (7.8)	18,048 (7.9)	
SBP, mean (SD), mmHg	129 (14.1)	129 (13.9)	129 (14.1)	<0.001
SBP group[b,c]				
Normal	77,876 (25.4)	18,973 (24.0)	58,903 (25.9)	<0.001
Prehypertension	85,904 (28.0)	22,533 (28.5)	63,371 (27.8)	
Hypertension Stage 1	75,660 (24.7)	19,742 (25.0)	55,918 (24.6)	
Hypertension Stage 2	67,239 (21.9)	17,797 (22.5)	49,442 (21.7)	

Abbreviation: AFib, atrial fibrillation; BMI, body mass index; CAD, coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DBP, diastolic blood pressure; IBD, inflammatory bowel disease; IQR, interquartile range; OSA, obstructive sleep apnea; SBP, systolic blood pressure; TIA, transient ischemic attack.

[a]In this table, figures for continuous variables are presented as mean (SD) or median (IQR) as appropriate, while figures for categorical variables are presented as counts and percentages. In each cell for categorical variables, the first number is the count of a specific measure, and the second is the percentage.

[b]Percentages provided may not sum up to 100% precisely due to rounding.

[c]There are missing values for BMI, DBP, and SBP. Patient counts with BMI for the overall, rural group and urban groups are 278,464, 61,008, and 227,651, respectively. Patient counts with DBP for the overall, rural group and urban group are 306,715, 79,064, and 227,651, respectively. Patient counts with SBP for the overall, rural group and urban group are 306,679, 79,045, and 227,634, respectively.

Additionally, cumulative incidence increased with advancing age, with the most significant rate seen in those aged 75+ (3.67%). Cumulative incidence was highest in patients with intracranial injury, cerebrovascular disease, stroke, Parkinson's disease, transient ischemic attack (TIA), and epilepsy. Geographically, urban populations generally had higher MCI cumulative incidences for most comorbidities, except for intracranial injury.

The MCI incidence rates by age groups revealed a consistent pattern of higher MCI incidence rates with increasing age, particularly pronounced in urban settings (Table 3 and Figure S3). The incidence rate per 1,000 person-years for patients aged 45-54 was slightly higher in rural (1.02; 95% CI, 0.81-1.23) compared to urban regions (0.97; 95% CI, 0.86-1.09). In contrast, urban populations demonstrated progressively higher incidence rates in older age groups, with a notable difference in the aged 75+ group, where urban incidence peaked at 13.1 (95% CI, 12.5-13.6) versus 9.13 (95% CI, 8.28-9.97) in rural areas.

3.3 | Comparison of utilization, referral, and diagnosis rates across geographies

Rural patients had a higher average number of healthcare encounters (mean 55.9, SD 74.2) compared to urban patients (mean 45.5, SD 65.2), as shown in Table 1. This pattern was consistent across different age groups and encounter settings, including emergency, inpatient, and outpatient services. However, we noticed a comparable proportion of patients received care from a PCP across rural (90.7%) and urban (89.1%) settings (Table S3). Furthermore, a further review of the healthcare encounters showed a significant portion of rural patients' encounters (30.1%) involve a PCP, compared to 22.8% for urban counterparts ($p < 0.05$). These findings suggest that rural patients have slightly higher access to primary healthcare services than urban patients within CHW. However, further analysis of the neurological services data in our dataset revealed distinct divergences in the subsequent healthcare journey for MCI management. Specifically, out of the 3,809 patients in the neurological services data, 802 (0.77%) of the rural population and 3,007 (0.94%) of the urban population were referred to neurological services; 415 (0.40%) of the rural patients and 1,666 (0.52%) of the urban patients completed the referral process. Urban residents showed a higher rate of referrals to neurological services and were more likely to complete these referrals compared to rural residents. Analyses indicated significant differences in both the likelihood of receiving a referral to neurological services and the completion rates of these referrals when comparing the entire rural and urban patient cohorts ($p < 0.05$). The MCI, dementia or AD diagnosis rate upon referral completion was 0.17% in urban areas, higher than the rate of 0.10% in rural. The geographic distribution of patient counts reveals a higher concentration in urban areas, as depicted by larger circle sizes in Figure S4. CHW hospitals are located in both urban and rural areas, suggesting widespread availability of healthcare services. However, rural areas exhibit more dispersed and smaller patient counts, indicating potential barriers to accessing specialized care. Additionally, the distribution of neurology department referrals shows a higher concentration in urban areas, indicating greater accessibility to neurological services in these regions. In contrast, rural areas exhibit fewer and more dispersed referrals, indicating potential barriers to accessing specialist care (Figure S5). In summary, while overall encounters

TABLE 2 MCI cumulative incidence by demographics and comorbidities[a].

Parameter	Overall	Rural	Urban
Total no. MCI	4,999/423,592 (1.18)	1,129/104,221 (1.08)	3,870/319,371 (1.21)
Sex			
Male	2,405/198,674 (1.21)	559/49,629 (1.13)	1,846/149,045 (1.24)
Female	2,594/224,918 (1.15)	570/54,592 (1.04)	2,024/170,326 (1.19)
Age group (years)			
45-54	377/120,000 (0.31)	93/26,887 (0.35)	284/93,113 (0.31)
55-64	833/139,523 (0.60)	201/34,559 (0.58)	632/104,964 (0.60)
65-74	1,518/102,218 (1.49)	387/26,907 (1.44)	1,131/75,311 (1.50)
75+	2,271/61,851 (3.67)	448/15,868 (2.82)	1,823/45,983 (3.96)
Ethnicity			
Hispanic	16/3,840 (0.42)	3/858 (0.35)	13/2,982 (0.44)
Race			
White	4,763/402,931 (1.18)	1,109/102,537 (1.08)	3,654/300,394 (1.22)
African American	227/18,770 (1.21)	16/1,043 (1.53)	211/17,727 (1.19)
Other	9/1,891 (0.48)	4/641 (0.62)	5/1,250 (0.40)
Diabetes	1,214/46,549 (2.61)	275/11,375 (2.42)	939/35,174 (2.67)
Hearing loss	579/21,234 (2.73)	69/2,792 (2.47)	510/18,442 (2.77)
Heart disease	403/12,666 (3.18)	78/3,039 (2.57)	325/9,627 (3.38)
Hyperlipidemia	2,637/120,951 (2.18)	502/25,365 (1.98)	2,135/95,586 (2.23)
Intracranial injury	72/1,440 (5.00)	18/350 (5.14)	54/1,090 (4.95)
Cerebrovascular	760/18,638 (4.08)	169/4,592 (3.68)	591/14,046 (4.21)
CKD	674/17,939 (3.76)	127/3,494 (3.63)	547/14,445 (3.79)
AFib	679/23,272 (2.92)	127/4,933 (2.57)	552/18,339 (3.01)
CAD	1,107/37,750 (2.93)	226/9,158 (2.47)	881/28,592 (3.08)
Stroke	576/14,447 (3.99)	130/3,629 (3.58)	446/10,818 (4.12)
Cancer	1,198/57,572 (2.08)	236/12,036 (1.96)	962/45,536 (2.11)
Parkinson's disease	128/1,529 (8.37)	16/325 (4.92)	112/1,204 (9.30)
IBD	339/14,498 (2.34)	48/2,736 (1.75)	291/11,762 (2.47)
Hyperthyroidism	75/3,973 (1.89)	10/700 (1.43)	65/3,273 (1.99)
TIA	273/6,673 (4.09)	50/1,543 (3.24)	223/5,130 (4.35)
Epilepsy	215/4,121 (5.22)	53/1,027 (5.16)	162/3,094 (5.24)
VB12 deficiency	30/1,252 (2.40)	6/429 (1.40)	24/823 (2.92)
MCI incidence by demographics and comorbidities			
OSA	881/42,717 (2.06)	167/8,419 (1.98)	714/34,298 (2.08)
Insomnia	743/31,075 (2.39)	107/5,149 (2.08)	636/25,926 (2.45)
COPD	638/22,502 (2.84)	186/7,206 (2.58)	452/15,296 (2.96)
Depression	1,168/49,104 (2.38)	225/9,645 (2.33)	943/39,459 (2.39)
BMI group[b]			
Normal weight	1,205/90,636 (1.33)	263/21,467 (1.23)	942/69,169 (1.36)
Underweight	75/4,484 (1.67)	15/1,296 (1.16)	60/3,188 (1.88)
Overweight	1,727/145,949 (1.18)	384/34,885 (1.10)	1,343/111,064 (1.21)
Obese	1,992/182,523 (1.09)	467/46,573 (1.00)	1,525/135,950 (1.12)

(Continues)

TABLE 2 (Continued)

Parameter	Overall	Rural	Urban
DBP group[b]			
Normal	3,644/258,486 (1.41)	809/63,620 (1.27)	2,835/194,866 (1.45)
Prehypertension	1,176/131,587 (0.89)	279/32,519 (0.86)	897/99,068 (0.91)
Hypertension	179/33,519 (0.53)	41/8,082 (0.51)	138/25,437 (0.54)
SBP group[b]			
Normal	1,099/107,583 (1.02)	233/25,259 (0.92)	866/82,324 (1.05)
Prehypertension	1,461/118,897 (1.23)	337/29,679 (1.14)	1,124/89,218 (1.26)
Hypertension Stage 1	1,294/104,257 (1.24)	310/25,938 (1.20)	984/78,319 (1.26)
Hypertension Stage 2	1,145/92,855 (1.23)	249/23,345 (1.07)	896/69,510 (1.29)

Abbreviations: AFib, atrial fibrillation; BMI, body mass index; CAD, coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DBP, diastolic blood pressure; IBD, inflammatory bowel disease; MCI, mild cognitive impairment; OSA, obstructive sleep apnea; SBP, systolic blood pressure; TIA, transient ischemic attack.

[a]In this table, each cell represents the number of MCI cases against the total number of patients in that subgroup, followed by the percentage.

[b]Cumulative incidences are calculated using denominators that have been adjusted through imputation to account for missing data.

TABLE 3 MCI incidence rates (per 1,000 person-years) and 95% CI by age groups in the primary analysis.

Age group (years)	Overall	Rural	Urban
45-54	0.98 (0.88, 1.08)	1.02 (0.81, 1.23)	0.97 (0.86, 1.09)
55-64	1.83 (1.71, 1.95)	1.69 (1.46, 1.92)	1.88 (1.73, 2.03)
65-74	4.54 (4.31, 4.77)	4.26 (3.83, 4.68)	4.65 (4.37, 4.92)
75+	12.0 (11.5, 12.5)	9.13 (8.28, 9.97)	13.1 (12.5, 13.6)

Abbreviations: CI, confidence interval; MCI, mild cognitive impairment.

were higher within rural patients, care specific to MCI diagnosis and management was lower.

3.4 | Risk factors for incident MCI

Univariate Cox analysis identified no significant associations for race, ethnicity, hyperthyroidism, and vitamin B12 deficiency in the rural population, while all covariates were significant in urban and overall populations (Table S4). Multivariate Cox regression highlighted urban residency as a significant risk factor for MCI (hazard ratio [HR] 1.15 [95% CI, 1.08-1.23]) (Table 4). Increased age was a common risk factor across settings, with the risk being notably higher among urban residents aged 75+ (HR 11.26 [95% CI, 9.88-12.82]) compared to their rural counterparts (HR 7.58 [95% CI, 6.02-9.55]). Females had a slightly reduced MCI risk across settings. Several other risk factors were associated with MCI incidence across settings. These included diabetes, intracranial injury, cerebrovascular disease, chronic kidney disease (CKD), stroke, Parkinson's disease, epilepsy, COPD, depression, and increased age, though the HRs varied. Body mass index (BMI) and diastolic blood pressure (DBP) were associated with a reduced risk of incident MCI, with specific HRs for rural and urban settings. Urban-specific risk factors included hearing loss, inflammatory bowel disease (IBD), obstructive sleep apnea (OSA), insomnia, being African American, and being underweight. The forest plot in Figure S6 visually highlights the rural-urban differences in risk factors.

3.5 | Sensitivity analyses

Complete-case analysis aligned with primary results, confirming the reliability of identified risk factors. Figure S7 shows the study flowchart for the extended sensitivity analysis, including patients who progressed directly to dementia or AD. The analysis consisted of 438,282 patients, 109,950 (25.1%) from rural areas and 328,332 (74.9%) from urban areas. MCI cases were identified in 6,080 (5.5%) rural patients and 15,005 (4.6%) urban patients. Our extended analysis revealed an overall MCI incidence rate of 15.4 per 1,000 person-years [95% CI, 15.19-15.60]. The rural group demonstrated a higher incidence rate of 17.03 per 1,000 person-years [95% CI, 16.61-17.46] contrasting with the urban subgroup incidence rate of 14.82 [95% CI, 14.58-15.06]. The analysis over age groups showed rural rates consistently exceeding urban rates across all age brackets (Table 5 and Figure S8). A marked increase was observed in the 65-74 cohort, with urban incidence at 15.4 per 1,000 person-years [95% CI, 14.9-15.9], and rural incidence peaking at 17.6 [95% CI, 16.7-18.5]. The most pronounced difference was found in the 75+ group, with urban incidence at 61.4 per 1,000 person-years [95% CI, 60.2-62.7], and rural rates highest at 66.5 [95% CI, 64.3-68.8].

3.6 | Factors contributing to patients skipping the MCI stage and progressing directly to dementia

The detailed analysis comparing the baseline characteristics of MCI diagnosed patients and MCI skippers is presented in Table S5 and Supplementary Text. Notably, MCI skippers are typically older, female, Hispanic, and have fewer encounters.

TABLE 4 HRs and 95% CIs in the multivariate cox model.

	Overall		Rural		Urban	
Characteristics	HR (95% CI)	*p*-value	HR (95% CI)	*p*-value	HR (95% CI)	*p*-value
Urbanization						
Rural	Ref.		—	—	—	—
Urban	1.15 (1.08, 1.23)	<0.001	—	—	—	—
Sex						
Male	Ref.		Ref.		Ref.	
Female	0.83 (0.78, 0.88)	<0.001	0.81 (0.72, 0.92)	<0.001	0.83 (0.78, 0.89)	<0.001
Age group (years)						
45-54	Ref.		Ref.		Ref.	
55-64	1.77 (1.57, 2.00)	<0.001	1.57 (1.23, 2.01)	<0.001	1.84 (1.60, 2.11)	<0.001
65-74	4.15 (3.70, 4.65)	<0.001	3.77 (3.00, 4.74)	<0.001	4.27 (3.75, 4.88)	<0.001
75+	10.27 (8.17, 11.51)	<0.001	7.58 (6.02, 9.55)	<0.001	11.26 (9.88, 12.82)	<0.001
Race						
White	Ref.		—	—	Ref.	
African Americans	1.53 (1.34, 1.75)	<0.001	—	—	1.54 (1.34, 1.78)	<0.001
Other	0.63 (0.33, 1.21)	0.16	—	—	0.55 (0.23, 1.33)	0.19
Diabetes	1.34 (1.24, 1.43)	<0.001	1.38 (1.19, 1.60)	<0.001	1.32 (1.22, 1.43)	<0.001
Hearing loss	1.18 (1.08, 1.29)	<0.001	—	—	1.17 (1.07, 1.29)	0.001
Intracranial injury	2.43 (1.91, 3.08)	<0.001	2.74 (1.71, 4.41)	<0.001	2.38 (1.81, 3.12)	<0.001
Cerebrovascular	1.34 (1.21, 1.49)	<0.001	1.36 (1.08, 1.72)	0.010	1.33(1.18, 1.50)	<0.001
CKD	1.21 (1.10, 1.32)	<0.001	1.41 (1.16, 1.72)	<0.001	1.17 (1.06, 1.29)	0.002
Stroke	1.22 (1.08, 1.37)	0.001	1.32 (1.02, 1.71)	0.03	1.19 (1.04, 1.36)	0.011
Parkinson's disease	3.23 (2.70, 3.85)	<0.001	2.40 (1.46, 3.95)	<0.001	3.40 (2.81, 4.11)	<0.001
IBD	1.14 (1.02, 1.27)	0.03	—	—	1.18 (1.04, 1.33)	0.008
Epilepsy	3.00 (2.60, 3.45)	<0.001	3.14 (2.36, 4.18)	<0.001	2.96 (2.52, 3.48)	<0.001
OSA	1.13 (1.05, 1.22)	0.002	—	—	1.13 (1.04, 1.24)	0.005
Insomnia	1.19 (1.09, 1.29)	<0.001	—	—	1.20 (1.10, 1.32)	<0.001
COPD	1.30 (1.20, 1.42)	<0.001	1.45 (1.23, 1.71)	<0.001	1.26 (1.13, 1.39)	<0.001
Depression	1.77 (1.65, 1.90)	<0.001	1.95 (1.67, 2.28)	<0.001	1.75 (1.61, 1.90)	<0.001
BMI group						
Normal weight	Ref.		Ref.		Ref.	
Underweight	1.39 (1.10, 1.75)	0.002	1.06 (0.63, 1.78)	0.84	1.50 (1.16, 1.95)	0.002
Overweight	0.83 (0.77, 0.90)	<0.001	0.84 (0.71, 0.98)	0.03	0.83 (0.77, 0.91)	<0.001
Obese	0.77 (0.71, 0.83)	<0.001	0.77 (0.66, 0.94)	0.001	0.78 (0.71, 0.85)	<0.001
DBP group						
Normal	Ref.		Ref.		Ref.	
Prehypertension	0.87 (0.81, 0.93)	<0.001	0.86 (0.75, 0.99)	0.03	0.87 (0.80, 0.94)	<0.001
Hypertension	0.74 (0.64, 0.86)	<0.001	0.68 (0.50, 0.94)	0.02	0.76 (0.64, 0.90)	0.002

Abbreviations: BMI, body mass index; CI, confidence interval; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DBP, diastolic blood pressure; HR, hazard ratio; IBD, inflammatory bowel disease; OSA, obstructive sleep apnea.

4 | DISCUSSION

Our study is the first to leverage EHR data to comprehensively explore MCI incidence, management, and associated risk factors across West Michigan. The stable categorization of patient residences into rural and urban areas using RUCA codes reinforces the validity and reliability of our findings, highlighting geographic differences in the risk and incidence of MCI. This study fills a critical gap in the existing literature, offering new insights into how geographical factors influence MCI risk. Our analysis highlights significant disparities in access to specialized

TABLE 5 MCI incidence rates (per 1,000 person-years) and 95% CI by age groups in the extended sensitivity analysis.

Age group (years)	Overall	Rural	Urban
45-54	2.46 (2.30, 2.62)	3.20 (2.84, 3.56)	2.23 (2.05, 2.40)
55-64	5.52 (5.31, 5.74)	6.51 (6.06, 6.97)	5.16 (4.92, 5.40)
65-74	16.0 (15.5,16.4)	17.6 (16.7, 18.5)	15.4 (14.9, 15.9)
75+	62.8 (61.7, 63.9)	66.5 (64.3, 68.8)	61.4 (60.2, 62.7)

Abbreviations: CI, confidence interval; MCI, mild cognitive impairment.

care between urban and rural areas. Urban patients are more likely to be diagnosed with MCI and have higher referral rates to neurological services, indicating better access to specialist care. In contrast, rural areas face challenges in accessing such services, potentially leading to a higher rate of underdiagnosis of MCI.

4.1 | Incidence rates and underdiagnosis implications

The primary analysis indicates a higher MCI incidence rate in urban areas. However, the results from the sensitivity analysis showed that rural areas had higher incidence across all age groups. This suggests that many rural patients may progress to dementia without an intermediate MCI diagnosis, indicating potential underdiagnosis in these regions. This is consistent with previous studies highlighting the challenges in diagnosing MCI. One study evaluating 40 million Medicare beneficiaries over 65, found that fewer than 8% of expected MCI cases were diagnosed.[29] Another study assessing 226,756 primary care clinicians reported that 99.9% of the clinicians had an observed diagnosis rate of MCI lower than the expected rate,[30] emphasizing the challenge in primary care settings. Furthermore, rural patients with early onset Alzheimer's disease and related dementias (ADRD) are notably less likely to undergo neuropsychological testing or consult psychologists, often relying solely on PCP visits for diagnosis and symptom management.[31] Our analysis aligns with these findings, indicating the systemic barriers to early MCI detection and access to specialist care in rural areas. This calls for the urgent need for enhanced diagnostic strategies and the importance of addressing the disparities in healthcare access.

4.2 | Healthcare access and continuity of care

The further exploration on healthcare access and continuity of care highlights an intriguing pattern: rural residents, despite similar access to PCPs, have fewer referrals to specialists and lower completion rates for neurological services. In contrast, urban individuals exhibit higher referral and completion rates for specialist services, highlighting an urban-rural divide in healthcare access. This discrepancy in care continuity, particularly pronounced with the higher normal-to-dementia progression rate in rural areas, underscores the urgent need for targeted healthcare strategies to improve access and reduce disparities. Addressing these gaps is essential to foster health equity and improve patient outcomes.

4.3 | Geographic distribution and specialist access

The mapping of patient counts, hospital locations, and neurology department referrals highlights significant disparities in healthcare accessibility between urban and rural areas. Despite the presence of CHW hospitals in both settings, rural areas show a lower concentration of patients and likely less access to specialized services, such as neurological care. These findings suggest that the lower rates of specialist referrals in rural areas may be influenced by accessibility challenges, leading to potential underdiagnosis of MCI. This underscores the need for targeted healthcare strategies to improve access and reduce care disparities in rural areas.

4.4 | Demographic factors in MCI risk

Consistent with prior studies, advancing age was the most prominent risk factor for MCI across settings. Increased risk was noted among urban seniors. This may indicate higher MCI diagnosis rates or life expectancies in urban seniors. Our findings also align with studies showing a lower hazard ratio for females than males, potentially due to hormonal and genetic protective factors related to MCI development.[32]

4.5 | Distinct urban MCI risk factors

Urban residency showed a higher hazard ratio for MCI. Several factors identified in the literature as contributors to cognitive decline were significantly associated with MCI risk in urban populations. These include hearing loss,[33] IBD,[34] OSA,[35] and insomnia.[36] Urban areas with higher levels of noise pollution and distinct stressors may exacerbate sleep disturbance,[37] contributing to cognitive decline. Interestingly, IBD is linked to chronic inflammation[38] and neurodegeneration,[39] while OSA is associated with hypoxia and sleep fragmentation,[40] both of which contribute to cognitive decline. Notably, our study reveals a higher risk of MCI among underweight individuals in urban areas. This could stem from distinct lifestyle and health-related behaviors in urban and rural environments. These findings highlight the need for more research on how the cause of a patient's weight, ranging from genetics to food access to physical activity, will influence MCI risk.

4.6 | BMI and DBP in MCI risk

Interestingly, DBP was inversely associated with MCI risk, which aligns with mixed results in existing literature,[41,42] This suggests that tar-

geted intervention, such as systolic hypertension reduction,[43] may be beneficial for MCI risk mitigation. Additionally, being overweight or obese was associated with a lower MCI risk, introducing the possibility of an "obesity paradox" in cognitive health, echoing phenomena observed in cardiovascular diseases.[44] Previous studies have also suggested that the association between BMI and MCI may be moderated by gender and age.[45] This complex finding highlights the need for further research to understand the biological mechanisms underlying this relationship.

4.7 | MCI risk factors across settings

Our findings revealed significant risk factors for MCI across settings, including depression, epilepsy, diabetes, and CKD. This aligns with prior research establishing contributors to cognitive decline.[46–49] Importantly, conditions such as diabetes and cerebrovascular diseases have modifiable elements, highlighting the potential for targeted interventions to mitigate MCI risk.

4.8 | Limitations and conclusions

Several limitations should be considered. The focus on West Michigan may affect the broader applicability of findings. Additionally, EHR data may introduce errors, and ICD codes may lead to an underestimation of true MCI incidence, as some individuals might remain undiagnosed or not seek medical attention. EHR data lacks certain risk factors that could impact MCI risk, including education level, physical and intellectual activities, and environmental factors like pollutants. These factors may confound the observed associations between urban/rural residency and MCI risk. Moreover, the assumption that all dementia patients first had MCI and the methodology and limitations of estimating MCI onset as the midpoint between initial encounter and dementia diagnosis are detailed in Supplementary Text. This assumption introduces certain limitations, particularly for individuals with rapidly progressing dementia or those whose cognitive decline may not follow a linear trajectory.

In conclusion, our study harnesses EHR data to reveal critical insights into MCI incidence, management, and risk factors across geographic settings. Sensitivity analysis suggests potential underdiagnosis of MCI in rural areas due to reduced access to specialists, as rural patients are more likely to be diagnosed with MCI than urban patients when assuming all dementia patients first had MCI. This highlights significant disparities in MCI diagnosis and specialized care access between rural and urban areas. Our findings underscore the importance of expanding healthcare navigation, PCP training, and rotating specialty clinics, among other efforts, to bridge urban-rural divides. We advocate for comprehensive policy and educational reforms to ensure equitable healthcare outcomes across all communities. Addressing these disparities can significantly impact the trajectory of cognitive decline, contributing to a broader effort to mitigate the prevalence of AD.

Future studies should explore how socioeconomics, environment, and lifestyle impact MCI. For instance, examining the relationship between air quality and MCI could reveal how environmental exposures contribute to cognitive health disparities. Building on existing research linking air pollution and dementia,[50] future investigations could provide a deeper understanding of how MCI varies with different environmental exposures. These insights could inform targeted public health strategies to mitigate MCI risk factors across diverse settings, enhancing the prevention and management of cognitive health conditions.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest. Author disclosures are available in the supporting information.

CONSENT STATEMENT

This study utilized de-identified Electronic Health Record (EHR) data and was approved by the Institutional Review Board (IRB) at Corewell Health West (CHW) and Michigan State University (MSU). Due to the retrospective nature of the study and the use of de-identified data, informed consent from individual patients was not required.

DATA AVAILABILITY STATEMENT

Due to the sensitive nature of EHR data from Corewell Health West, including privacy and confidentiality concerns, our dataset cannot be shared.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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