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Regional Disparities in the Infant Mortality Rate in Korea Between 2001 and 2021

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Conceptualization: Kim JS, Woo H. Data curation: Kim JS, Woo H. Formal analysis: Kim JS, Woo H. Investigation: Kim JS, Woo H. Methodology: Woo H. Validation: Kim JS. Writing - original draft: Kim JS, Woo H. Writing - review & editing: Kim JS, Woo H.

ABSTRACT

Background: The infant mortality rate (IMR) has been considered an important indicator of the overall public health level. Despite improvements in recent decades, regional inequalities in the IMR have been reported worldwide. However, there are no Korean epidemiological studies on regional disparities in the IMR.
Methods: We extracted causes of death data from the Statistics Korea through the Korean Statistical Information Service database between 2001 and 2021. The total and regional IMRs were calculated to determine regional disparities. Based on causes of death and using Seoul as a reference, the excess infant deaths and population attributable fractions (PAFs) were calculated for 15 other metropolitan cities and provinces. The average annual percent changes by region from 2001 to 2021 were obtained using a joinpoint regression program. To assess inequities in IMR trends, the rate ratios (RRs) and rate differences (RDs) of the 15 regions were calculated by dividing the study period into period 1 (2001–2007), period 2 (2008–2014), and period 3 (2015–2021).
Results: The overall IMR in Korea was 3.64 per 1,000 live births, and the IMRs in the 14 regions were relatively higher than that in Seoul, with RRs ranging from 1.15 (95% confidence interval [CI], 1.04, 1.27) in Jeju-do to 1.62 (95% CI, 1.54, 1.71) in Daegu, over the total study period. Significant differences in infant deaths by region were observed for all causes of death, with PAFs ranging from 2.2% (95% CI, 1.7, 2.6) in Gyeonggi-do to 38.4% (95% CI, 38.1, 38.6) in Daegu. The leading cause of excess infant deaths was perinatal problems. The IMR disparities in the relative and absolute measures decreased from 1.44 (1.34, 1.54) to 1.21 (1.10, 1.31) for RRs and from 0.79 (0.63, 0.96) to 0.30 (0.15, 0.45) for RDs between periods 1 and 2, followed by an increase from 1.21 (1.10, 1.31) to 1.36 (1.21, 1.53) for RRs and from 0.30 (0.15, 0.45) to 0.51(0.36, 0.67) for RDs between period 2 and 3.
Conclusion: Infant death is associated with place of residence and regional gaps have recently widened again in Korea. An in-depth investigation of the causes of regional disparities in infant mortality is required for effective governmental policies to achieve equality in infant health.

Keywords: Infant Mortality; Child Mortality; Health Inequities; Korea

INTRODUCTION

The infant mortality rate (IMR) is defined as the number of infants who die within the first year of life for every 1,000 live births in a given period. The IMR is considered a key indicator of the overall public health level because it has a strong correlation with medical factors such as infection and the quality of pre- and postnatal care as well as nonmedical exogenous factors such as nutrition, culture, and socioeconomic determinants of health.[1]

Although the IMR has significantly declined worldwide in recent decades, it has been reported that inequalities and disparities in the IMR still exist across and even within countries, with variations by race, ethnicity, state, and region. In the United States, infants born to black, non-Hispanic women had the highest IMR, and significant differences in infant mortality by state were also observed.[2-4] The United Kingdom, Japan, Canada and China also have substantial geographic disparities in infant deaths associated with region and rurality.[5-8] Therefore, governmental efforts to reduce the gap in the IMR, including understanding the differences in infant mortality due to various factors and establishing proper interventions to reduce preventable infant deaths, are ongoing challenges in many countries.

Despite homogeneity of race, ethnicity, culture and geography in Korea, regional disparities in the overall public health level have been reported.[9,10] Although the IMR has improved over time in Korea, little is known about regional differences in the IMR.[11-14] Recently, pediatric departments have been experiencing a medical crisis due to the rapidly decreasing application rate of pediatric residents, resulting in a shortage of pediatricians.[15,16] Many hospitals have decided to temporarily not offer pediatric emergency, intensive care or hospitalization treatment due to a lack of medical staff, especially in noncapital areas.[15] This phenomenon exacerbates regional inequalities in pediatric care accessibility and, in turn, may increase regional disparities in the IMR in Korea. A better understanding of the regional differences in the IMR is essential to establish proper interventions to resolve IMR disparities and reduce preventable infant deaths as well as to indirectly estimate the differences in the overall public health level among regions. However, little is known about regional differences in the IMR, and there are no studies that have well described descriptive statistics on regional disparities in the IMR in Korea.

Therefore, in this study, we aimed to examine whether there are regional disparities in the overall and cause-specific IMR in Korea using vital statistics. We also investigated the differences in IMR trends by region in terms of both rate differences (RDs) and rate ratios (RRs).

METHODS

Data sources

All mortality and population data were extracted from the Korean Statistical Information Service database between 2001 and 2021. The number of deaths at age 0 by the underlying cause of death based on International Classification of Diseases 10th Revision codes was extracted for each year and region. Population data by region were obtained from the mid-year population for each year. The level of regional classification was limited to 17 administrative divisions (provinces and metropolitan cities) for data stability. However, Sejong was excluded from the present study, which started generating data after 2012, so we only calculated IMRs between 2012 and 2021. Since 2001, vital statistics have been supplemented through infant cremation report data and neonatal death data. Therefore, data before 2001, which were many missing infant deaths, were excluded from the analysis.[9]

Statistical analysis

First, the average IMRs per 1,000 population by region were calculated from 2001 to 2021 to determine whether there were regional disparities in the IMR in Korea. The relative regional disparities in the IMR were identified through the RRs using the region with the lowest IMR as a reference group. The standard errors were calculated using the Taylor series expansion method to obtain the 95% confidence intervals (CIs) of the RR.[17]

Second, infant mortality attributable to regional disparities between 2001 and 2021 was analyzed by cause of death. The cause of death was classified, considering the number of infant deaths by cause in Korea between 2001 and 2021 and clinical relevance (**Table 1**). The expected number of deaths was calculated by applying the IMR of the reference group by cause of death to the number of births in each region. The mortality attributable to regional disparities was presented as excess deaths and the region-specific population attributable fraction, defined as the fraction of excess deaths divided by observed deaths compared with the reference group. The 95% CIs of the fraction were obtained using Monte Carlo simulation under the assumption of a Poisson distribution.[18]

Finally, an analysis of regional disparities in IMR trends was conducted. Previous studies have reported that the IMR in Korea has been continuously declining, and we analyzed the IMR trend in 16 provinces and metropolitan cities using the *Joinpoint* regression method to confirm whether the IMR trends in each region are similar.[11-14] The annual percent change (APC) in the IMR by region was calculated. More specifically, a maximum of two join points was set for each model, and the average APCs (AAPCs) were calculated for each segment.[19,20] *Joinpoint* regression can analyze decreasing trends in infant mortality by region, but it is difficult to accurately represent regional disparities in infant mortality trends. Therefore, the 21-year period from 2001 to 2021 was divided into 3 periods of 7 years each (period 1: 2001–2007, period 2: 2008–2014, period 3: 2015–2021), and the relative and absolute difference trends were examined to obtain the RRs and RDs in the IMR trend by region compared to those

Table 1. Causes of death (code classification)

Codes	Korean Standard Classification of Diseases, KCD-7	No.	This study	No.
P00–P96	Certain conditions originating in the perinatal period	16,627	Perinatal problems	16,627
Q00–Q99	Congenital malformations, deformations, and chromosomal abnormalities	6,520	Congenital anomalies	6,520
R00–R99	Symptoms, signs, and abnormal clinical and laboratory findings, NEC	3,969	Shock and ill-defined conditions	3,969
V01–Y98, U12	External causes of morbidity and mortality	1,696	Injury and external causes	1,696
I00–I99,	Diseases of the circulatory system	1,052	Circulatory and respiratory problems	1,052
J00–J98, U04	Diseases of the respiratory system			
G00–G98	Diseases of the nervous system	622	Nervous system problems	622
C00–D48,	Neoplasms	538	Cancer, blood and immune system problems	538
D50–D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune system			
A00–B99, U07.1, U07.2, U10	Certain infectious and parasitic diseases	368	Other causes	858
E00–E88	Endocrine, nutritional, and metabolic diseases	279		
K00–K92	Diseases of the digestive system	143		
N00–N98	Diseases of the genitourinary system	45		
M00–M99	Diseases of the musculoskeletal system and connective tissue	15		
L00–L98	Diseases of the skin and subcutaneous tissue	6		
F01–F99	Mental and behavioral disorders	1		
H00–H57	Diseases of the eye and adnexa	1		

of the reference group. Monte-Carlo simulation was performed using R version 4.2.2, and *Joinpoint* Regression Program version 4.9.1.0 (National Cancer Institute, Bethesda, MD, USA) was used for *Joinpoint* regression analysis.

Ethics statement

The Institutional Review Board (IRB) of Kyungpook National University Chilgok Hospital reviewed the protocol of this study and approved an exemption, the requirement for informed consent was waived because of the nature of public data from the Korean Statistical Information Service database (IRB No. 2023-02-006).

RESULTS

Regional disparities in the IMR between 2001 and 2021

Excluding Sejong, there were a total of 8,753,602 live births and 31,881 infant deaths in Korea from 2001 to 2021. The overall IMR in Korea was 3.64 per 1,000 live births between 2001 and 2021. Significant regional differences in IMRs were observed over the study period, and the IMR in metropolitan cities and provinces ranged from 3.13 per 1,000 live births in Seoul to 5.08 per 1,000 live births in Daegu.

The relative regional disparities in the IMR in Korea were assessed with RRs and 95% CIs and compared between Seoul, which was defined as the reference group because it had the lowest IMR in Korea, and the other 15 regions. The 14 regions showed significantly higher IMRs than Seoul, with RRs ranging from 1.15 (95% CI, 1.04–1.27) in Jeju-do to 1.62 (95% CI, 1.54–1.71) in Daegu. Only the IMR in Gyonggi-do, which is located adjacent to Seoul and one of the Seoul Capital Areas, was not significantly different compared to that of Seoul (RR, 1.02; 95% CI, 0.99–1.06). Interestingly, Gyeongsangbuk-do, which is located adjacent to Daegu and often referred to as Daegu-Gyeougbuk, had the second highest IMR (4.44 per 1,000 live births) and RR (RR, 1.42; 95% CI, 1.35–1.49). The IMRs in Jeollabuk-do (RR, 1.40; 95% CI, 1.32–1.49), Busan (RR, 1.33; 95% CI, 1.27–1.40), and Gangwon-do (RR, 1.27; 95% CI, 1.19–1.36) were also relatively high (**Table 2**).

Total and cause-specific excess infant mortality by region

Between 2001 and 2021, 14.0% (95% CI, 13.6–14.4) of infant deaths in Korea were attributable to regional disparities. If Seoul's IMR was applied to all live births in Korea, 4,455 infant deaths could have been prevented. In Korea, 16.1% of the deaths due to perinatal problems (P00–P96), 6.3% of the deaths due to congenital anomalies (Q00–Q99), 8.3% of the deaths due to shock and ill-defined conditions (R00–R99), 35.9% of the deaths due to injury and external causes (V01–Y89, U12), 19.9% of the deaths due to circulatory and respiratory problems (I00–I99, J00–J98, U04), 11.3% of the deaths due to nervous system problems (G00–G98) and 7.0% of the deaths due to cancer and blood problems (C00–D98) were attributable to regional disparities. If this is expressed as the number of excess deaths compared to Seoul, it corresponds to 2,675, 413, 328, 609, 209, 71, 38, and 114 deaths, respectively. Perinatal problems comprised the greatest portion, accounting for 60% (2,675/4,455) of all excess infant deaths. The main causes of excess infant death were perinatal problems, congenital anomalies and injury and external causes, which accounted for 83% (3,697/4455) of excess infant deaths in Korea (**Table 3** and **Fig. 1**).

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Table 2. IMRs and measures of disparities for South Korea and 17 administrative divisions (provinces and metropolitan cities) (2001–2021)

Location	Live births (mid-year population)	Sex ratio at birth	Infant deaths	IMR per 1,000 live births	Rate ratio (95% CI)
South Korea[a]	8,753,602	1.067	31,881	3.64	1.16 (1.13, 1.20)
Seoul	1,682,701	1.066	5,272	3.13	Ref.
Busan	515,012.5	1.067	2,151	4.18	1.33 (1.27, 1.40)
Daegu	399,323	1.081	2,030	5.08	1.62 (1.54, 1.71)
Incheon	491,814.5	1.061	1,874	3.81	1.22 (1.15, 1.28)
Gwangju	236,582	1.070	994	3.77	1.20 (1.12, 1.29)
Daejeon	272,911	1.070	1,037	3.80	1.21 (1.13, 1.30)
Ulsan	218,307.5	1.084	797	3.65	1.17 (1.08, 1.26)
Sejong[b]	26,137.5	1.039	60	2.30	-
Gyeonggi-do	2,260,165.5	1.058	7,237	3.20	1.02 (0.99, 1.06)
Gangwon-do	241,273.5	1.065	961	3.98	1.27 (1.19, 1.36)
Chungcheongbuk-do	272,318.5	1.065	997	3.66	1.17 (1.09, 1.25)
Chungcheongnam-do	368,462.5	1.063	1,364	3.70	1.18 (1.11, 1.25)
Jeollabuk-do	304,110	1.066	1,338	4.40	1.40 (1.32, 1.49)
Jeollanam-do	315,783.5	1.059	1,145	3.63	1.16 (1.09, 1.23)
Gyeongsangbuk-do	446,322	1.089	1,983	4.44	1.42 (1.35, 1.49)
Gyeongsangnam-do	587,677.5	1.080	2,290	3.90	1.24 (1.18, 1.31)
Jeju-do	113,837.5	1.080	411	3.61	1.15 (1.04, 1.27)

IMR = infant mortality rate, CI = confidence interval.
[a]Except Sejong; [b]2012–2021.

Table 3. Infant mortality attributable to regional disparities for South Korea and 16 administrative divisions (2001–2021)

Location	Cause of death	Observed	Expected	Excess	Attributable fraction (95% CI)
Korea	Total	31,881	27,426	4,455	14.0% (13.6, 14.4)
	P00–P96	16,627	13,952	2,675	16.1% (15.5, 16.6)
	Q00–Q99	6,520	6,107	413	6.3% (5.3, 7.2)
	R00–R99	3,969	3,641	328	8.3% (6.9, 9.4)
	V01–Y98, U12	1,696	1,087	609	35.9% (34.6, 37.5)
	I00–I99, J00–J98, U04	1,052	843	209	19.9% (17.8, 22.0)
	G00–G98	622	551	71	11.3% (8.2, 14.1)
	C00–D89	537	499	38	7.0% (3.2, 9.7)
	Other	858	744	114	13.3% (10.7, 15.5)
Seoul	Total	5,272	5,272	0	-
	P00–P96	2,682	2,682	0	-
	Q00–Q99	1,174	1,174	0	-
	R00–R99	700	700	0	-
	V01–Y98, U12	209	209	0	-
	I00–I99, J00–J98, U04	162	162	0	-
	G00–G98	106	106	0	-
	C00–D89	96	96	0	-
	Other	143	143	0	-
Busan	Total	2,151	1,614	537	25.0% (24.7, 25.3)
	P00–P96	1,209	821	388	32.1% (31.7, 32.5)
	Q00–Q99	459	359	100	21.7% (20.9, 22.4)
	R00–R99	240	214	26	10.7% (9.5, 11.9)
	V01–Y98, U12	87	64	23	26.5% (24.9, 28.3)
	I00–I99, J00–J98, U04	46	50	−4	−7.8% (−11.0, −4.9)
	G00–G98	47	32	15	31.0% (28.4, 32.8)
	C00–D89	28	29	−1	−4.9% (−9.8, −1.9)
	Other	35	44	−9	−25.0% (−29.0, −21.2)
Daegu	Total	2,030	1,251	779	38.4% (38.1, 38.6)
	P00–P96	1,296	636	660	50.9% (50.6, 51.2)
	Q00–Q99	343	279	64	18.8% (17.9, 19.5)
	R00–R99	159	166	−7	−4.5% (−6.0, −3.2)
	V01–Y98, U12	81	50	31	38.8% (37.5, 40.2)
	I00–I99, J00–J98, U04	44	38	6	12.6% (10.4, 15.0)
	G00–G98	35	25	10	28.1% (26.0, 30.5)
	C00–D89	32	23	9	28.8% (26.3, 30.8)
	Other	40	34	6	15.2% (12.5, 17.2)

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Table 3. (Continued) Infant mortality attributable to regional disparities for South Korea and 16 administrative divisions (2001–2021)

Location	Cause of death	Observed	Expected	Excess	Attributable fraction (95% CI)
Incheon	Total	1,874	1,541	333	17.8% (17.4, 18,1)
	P00–P96	983	784	199	20.3% (19.8, 20.7)
	Q00–Q99	365	343	22	6.0% (4.9, 6.9)
	R00–R99	226	205	21	9.5% (8.4, 10.7)
	V01–Y98, U12	116	61	55	47.3% (46.3, 48.5)
	I00–I99, J00–J98, U04	66	47	19	28.3% (26.4, 30.2)
	G00–G98	27	31	−4	−14.7% (−18.9, −10.8)
	C00–D89	34	28	6	17.5% (14.5, 20.0)
	Other	57	42	15	26.7% (24.6, 28.6)
Gwangju	Total	994	826	168	16.9% (16.5, 17.3)
	P00–P96	457	420	37	8.1% (7.5, 8.7)
	Q00–Q99	223	184	39	17.5% (16.7, 18.3)
	R00–R99	150	110	40	26.9% (25.9, 27.8)
	V01–Y98, U12	60	33	27	45.4% (44.4, 46.7)
	I00–I99, J00–J98, U04	32	25	7	20.7% (18.5, 22.7)
	G00–G98	31	17	14	46.4% (44.9, 48.0)
	C00–D89	22	15	7	31.6% (28.9, 33.4)
	Other	19	22	−3	−17.9% (−21.7, −14.6)
Daejeon	Total	1,037	855	182	17.5% (17.2, 17.9)
	P00–P96	500	435	65	13.0% (12.5, 13.6)
	Q00–Q99	245	190	55	22.3% (21.5, 23.0)
	R00–R99	120	114	6	5.4% (4.2, 6.7)
	V01–Y98, U12	55	34	21	38.4% (37.2, 39.9)
	I00–I99, J00–J98, U04	38	26	12	30.9% (29.1, 32.7)
	G00–G98	27	17	10	36.3% (34.2, 38.1)
	C00–D89	28	16	12	44.4% (42.8, 46.2)
	Other	24	23	1	3.4% (0.5, 6.1)
Ulsan	Total	797	684	113	14.2% (13.8, 14.6)
	P00–P96	432	348	84	19.5% (19.0, 19.9)
	Q00–Q99	142	152	−10	−7.3% (−8.5, −6.3)
	R00–R99	96	91	5	5.4% (4.2, 6.7)
	V01–Y98, U12	54	27	27	49.8% (48.7, 50.8)
	I00–I99, J00–J98, U04	17	21	−4	−23.6% (−26.8, −19.7)
	G00–G98	20	14	6	31.2% (29.3, 33.6)
	C00–D89	15	12	3	17.0% (14.5, 20.0)
	Other	21	19	2	11.7% (8.8, 13.8)
Gyeonggi-do	Total	7,237	7,081	156	2.2% (1.7, 2.6)
	P00–P96	3,702	3,602	100	2.7% (2.1, 3.4)
	Q00–Q99	1,429	1,577	−148	−10.3% (−11.6, −9.3)
	R00–R99	958	940	18	1.9% (0.6, 3.2)
	V01–Y98, U12	395	281	114	28.9% (27.4, 30.7)
	I00–I99, J00–J98, U04	276	218	58	21.2% (19.2, 23.4)
	G00–G98	136	142	−6	−4.7% (−8.8, −1.7)
	C00–D89	127	129	−2	−1.5% (−5.7, 1.6)
	Other	214	192	22	10.2% (7.9, 13.0)
Gangwon-do	Total	961	756	205	21.3% (21.0, 21.7)
	P00–P96	502	385	117	23.4% (22.9, 23.9)
	Q00–Q99	179	168	11	6.0% (4.9, 6.9)
	R00–R99	121	100	21	17.1% (16.0, 18.2)
	V01–Y98, U12	68	30	38	55.9% (55.1, 56.9)
	I00–I99, J00–J98, U04	33	23	10	29.6% (28.0, 31.7)
	G00–G98	13	15	−2	−16.9% (−21.1, −12.9)
	C00–D89	10	14	−4	−37.6% (−45.2, −34.1)
	Other	35	21	14	41.4% (39.7, 42.8)
Chungcheongbuk-do	Total	997	853	144	14.4% (14.0, 14.8)
	P00–P96	442	434	8	1.8% (1.2, 2.4)
	Q00–Q99	238	190	48	20.2% (19.3, 20.9)
	R00–R99	158	113	45	28.3% (27.3, 29.1)
	V01–Y98, U12	55	34	21	38.5% (37.2, 39.9)
	I00–I99, J00–J98, U04	37	26	11	29.1% (27.4, 31.2)
	G00–G98	19	17	2	9.7% (6.9, 12.7)
	C00–D89	14	16	−2	−11.0% (−16.3, −8.0)
	Other	34	23	11	31.9% (30.1, 33.7)

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Table 3. (Continued) Infant mortality attributable to regional disparities for South Korea and 16 administrative divisions (2001–2021)

Location	Cause of death	Observed	Expected	Excess	Attributable fraction (95% CI)
Chungcheongnam-do	Total	1,364	1,154	210	15.4% (15.0, 15.8)
	P00–P96	687	587	100	14.5% (14.0, 15.1)
	Q00–Q99	271	257	14	5.1% (4.1, 6.0)
	R00–R99	199	153	46	23.0% (22.0, 23.9)
	V01–Y98, U12	83	46	37	44.9% (43.6, 46.0)
	I00–I99, J00–J98, U04	47	35	12	24.5% (22.9, 26.9)
	G00–G98	17	23	−6	−36.5% (−42.5, −32.4)
	C00–D89	19	21	−2	−10.6% (−14.1, −5.9)
	Other	41	31	10	23.6% (21.3, 25.4)
Jeollabuk-do	Total	1,338	953	385	28.8% (28.5, 29.1)
	P00–P96	679	485	194	28.6% (28.2, 29.0)
	Q00–Q99	281	212	69	24.5% (23.7, 25.2)
	R00–R99	189	127	62	33.1% (32.2, 33.8)
	V01–Y98, U12	67	38	29	43.6% (42.3, 44.8)
	I00–I99, J00–J98, U04	46	29	17	36.4% (34.7, 38.0)
	G00–G98	25	19	6	23.4% (20.6, 25.5)
	C00–D89	20	17	3	13.3% (10.6, 16.4)
	Other	31	26	5	16.6% (14.3, 18.8)
Jeollanam-do	Total	1,145	989	156	13.6% (13.2, 14.0)
	P00–P96	520	503	17	3.2% (2.6, 3.8)
	Q00–Q99	238	220	18	7.4% (6.5, 8.4)
	R00–R99	158	131	27	16.9% (15.7, 17.9)
	V01–Y98, U12	92	39	53	57.4% (56.4, 58.2)
	I00–I99, J00–J98, U04	47	30	17	35.3% (33.8, 37.2)
	G00–G98	30	20	10	33.7% (31.5, 35.6)
	C00–D89	26	18	8	30.7% (28.1, 32.6)
	Other	34	27	7	21.1% (19.1, 23.2)
Gyeongsangbuk-do	Total	1,983	1,398	585	29.5% (29.2, 29.8)
	P00–P96	1,110	711	399	35.9% (35.5, 36.3)
	Q00–Q99	374	311	63	16.7% (15.9, 17.5)
	R00–R99	222	186	36	16.4% (15.2, 17.3)
	V01–Y98, U12	114	55	59	51.4% (50.3, 52.4)
	I00–I99, J00–J98, U04	65	43	22	33.9% (32.5, 35.9)
	G00–G98	25	28	−3	−12.5% (−16.7, −8.9)
	C00–D89	23	25	−2	−10.7% (−14.1, −5.9)
	Other	50	38	12	24.1% (21.9, 26.1)
Gyeongsangnam-do	Total	2,290	1,841	449	19.6% (19.2, 20.0)
	P00–P96	1,227	937	290	23.7% (23.2, 24.1)
	Q00–Q99	473	410	63	13.3% (12.4, 14.1)
	R00–R99	218	244	−26	−12.1% (−13.7, −10.6)
	V01–Y98, U12	137	73	64	46.7% (45.6, 47.9)
	I00–I99, J00–J98, U04	83	57	26	31.8% (30.1, 33.7)
	G00–G98	53	37	16	30.2% (27.6, 32.1)
	C00–D89	35	34	1	4.2% (1.5, 8.1)
	Other	64	50	14	24.1% (19.8, 24.0)
Jeju-do	Total	411	357	54	13.2% (12.8, 13.6)
	P00–P96	199	181	18	8.8% (8.2, 9.4)
	Q00–Q99	86	79	7	7.6% (6.6, 8.5)
	R00–R99	55	47	8	13.9% (12.7, 15.0)
	V01–Y98, U12	23	14	9	38.5% (37.2, 39.9)
	I00–I99, J00–J98, U04	13	11	2	15.7% (13.5, 18.0)
	G00–G98	11	7	4	34.8% (32.9, 36.9)
	C00–D89	8	6	2	18.8% (15.7, 21.1)
	Other	16	10	6	39.5% (38.0, 41.2)

CI = confidence interval.

Regional disparities attributable to infant deaths ranged from 2.2% (95% CI, 1.7–2.6) in Gyeonggi-do to 38.4% (95% CI, 38.1–38.6) in Daegu. Perinatal problems were the leading cause of excess infant deaths in all regions except Gwangju, Gyeonggi-do, Chungcheongbuk-do, and Jeollanam-do. In Daegu and Gyeongsangbuk-do, where the number of excess infant

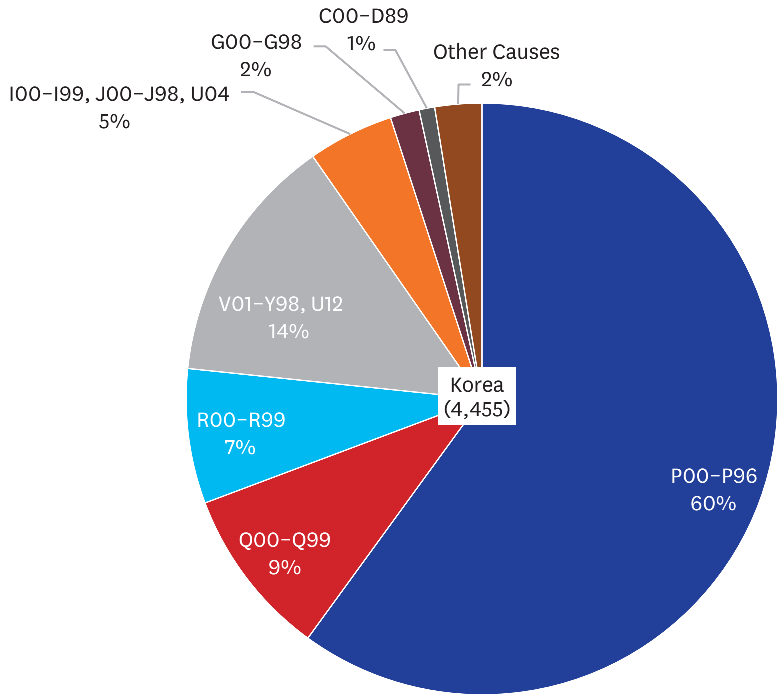

Fig. 1. Estimated excess number of deaths attributable to regional disparities and disease distribution in Korea.

deaths was the highest, perinatal problems accounted for 84.7% (660/779) and 68.2% (399/585) of the total excess infant deaths, respectively. Shock and ill-defined conditions in Gwangju, congenital anomalies in Chungcheongbuk-do, and injury and external causes in Gyeonggi-do and Jeollanam-do were the leading causes of excess infant deaths (**Table 3**). Overall, the proportion of excess deaths due to perinatal problems was high in the metropolitan cities (metropolitan cities: 68% vs. provinces: 53%), and the proportion of excess deaths due to injury and external causes was high in the provinces (metropolitan cities: 9% vs. provinces: 18%) (**Supplementary Fig. 1**).

Overall and regional trends in the IMRs between 2001 and 2021

The overall IMR in Korea significantly decreased over the study period (AAPC, −3.7%, 95% CI, −4.6%, −2.7%). The IMR decreased significantly in all regions except Chungcheongbuk-do, and the AAPCs ranged from −5.4% (95% CI, −6.7%, −4.0%) in Gwangju to −3.0% (95% CI, −3.6%, 2.3%) in Incheon. Specifically, the trend of change in the overall IMR in Korea showed that the IMR decreased rapidly between 2003 and 2008 (APC, −8.0%), but the rate of decline slowed between 2008 and 2021 (APC, −2.5%). During the same period, Seoul's APC was −4.3%, which means that, on average, the overall disparity in the IMR compared to that in Seoul decreased at the beginning of the observation period, but the overall disparity in the IMR compared to that in Seoul increased again after 2008. Excluding Seoul from the calculation of infant mortality in Korea, the gap has widened slightly since 2008 (**Fig. 2**, **Supplementary Figs. 2** and **3**).

The absolute and relative regional disparities in IMR trends were compared between Seoul (reference group) and the other 15 regions using RRs and RDs with 95% CIs according to period (**Figs. 3** and **4**). In Korea, there was a decrease in the RD and RR from period 1 (between 2001 and 2007) to period 2 (between 2008 and 2014) followed by an increase

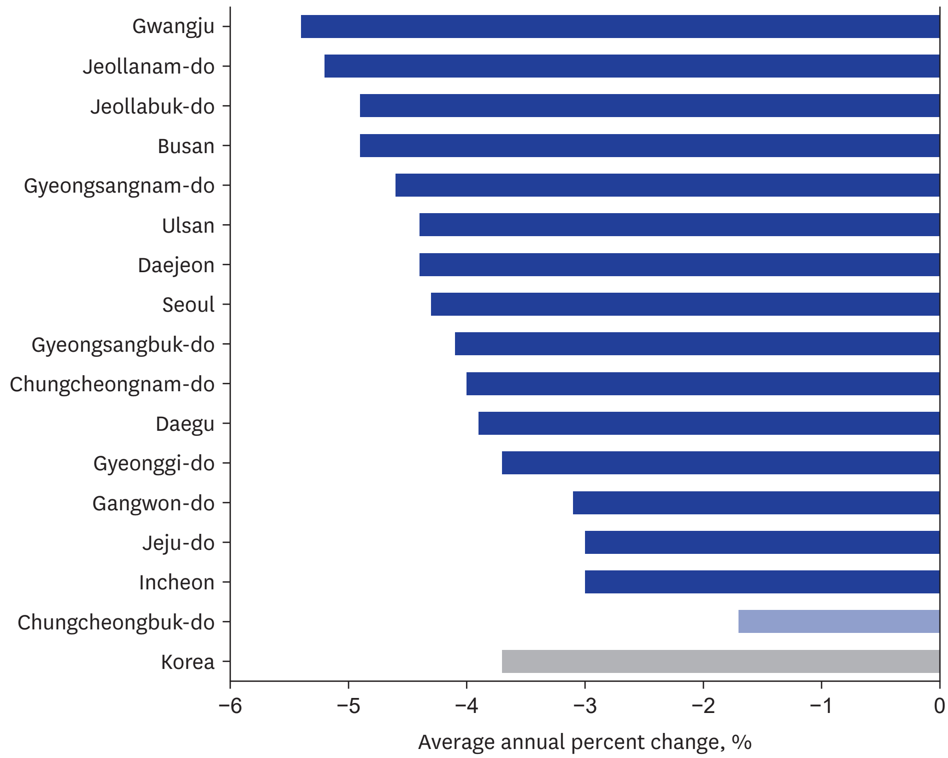

Fig. 2. Changes in the infant mortality rate in Korea (2001–2021). Dark blue and gray bars indicate statistical significance ($P < 0.05$).

from period 2 (between 2008 and 2014) to period 3 (between 2015 and 2021). By region, the RDs and RRs were similar to the overall trend in Korea, but in Gwangju, Jeollabuk-do, and Jeollanam-do, the RDs and RRs decreased throughout the study period. In Gangwon-do, the RD and RR increased from period 1 to period 2 and decreased from period 2 to period 1. **Supplementary Figs. 4** and **5** present cause-specific IMR trends during the study period.

DISCUSSION

We examined regional disparities in the IMR in Korea using cause of death statistics from the National Statistical Office, which covers the entire country. There have been discussions about the regional disparities in the IMR in Korea, but little is known about this issue.

We identified that regional disparities in the IMR exist in Korea. The region with the lowest IMR between 2001 and 2021 was Seoul; except for that in Gyeonggi-do during period 2, the IMR was consistently low in Seoul compared to other regions from period 1 to period 3. Considering the proportion of excess deaths due to perinatal problems in other regions, the low IMR in Seoul can be mainly explained by the lower IMR due to perinatal causes compared to those in other regions. Notably, as reported in previous studies, Korea's IMR has been declining; the relative and absolute disparities have tended to increase in recent years.[11-14] This is because the decline in IMR in other regions has slowed compared to that in Seoul, and various causes, including the distribution of medical resources, social determinants of health, and the physical environment, need to be considered to determine the cause.[21]

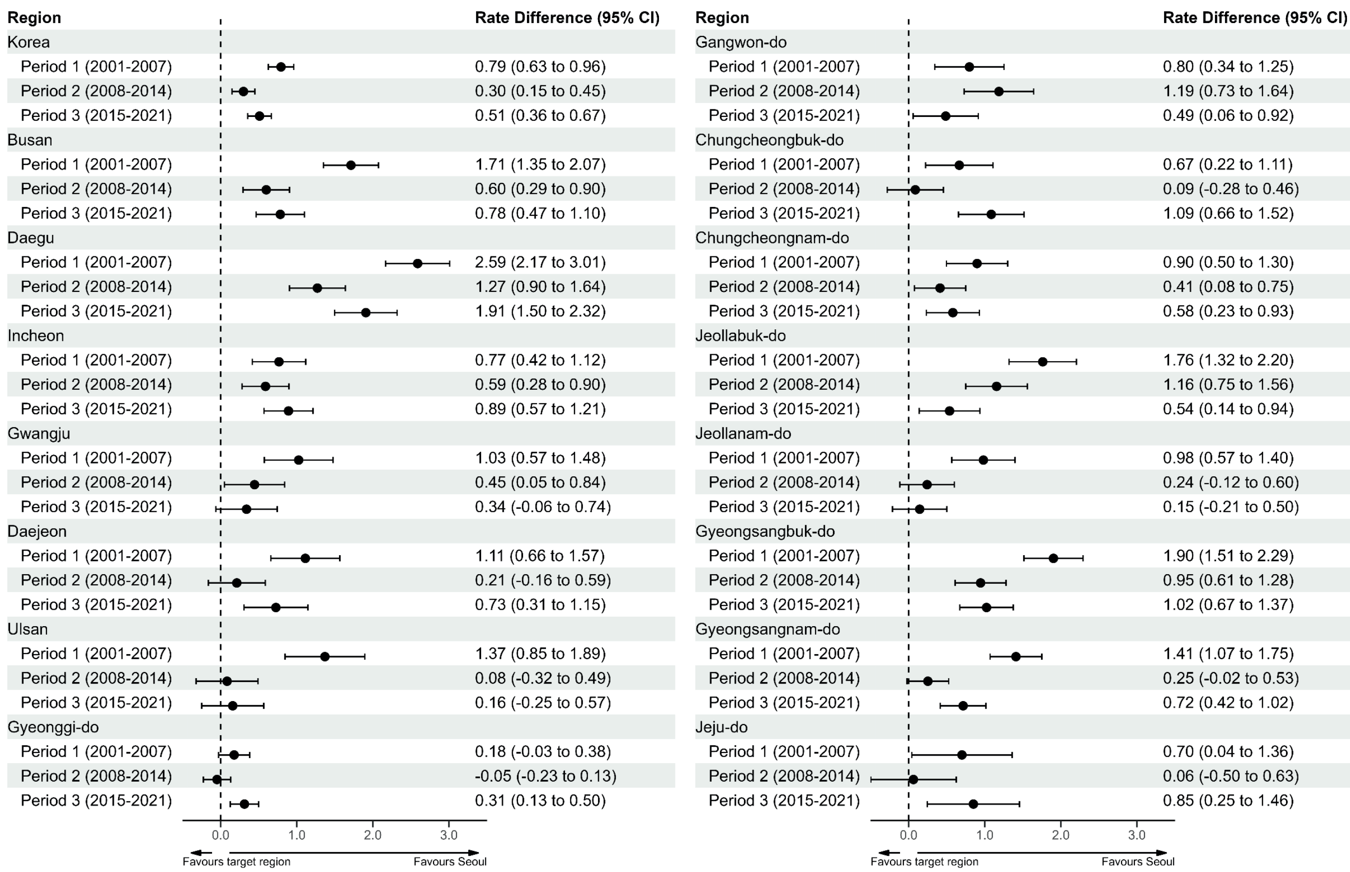

Fig. 3. Trends in the rate difference of infant mortality by region in Korea.
CI = confidence interval.

Although our study focused on the phenomenon of regional disparities in the IMR rather than on causal relationships, regional differences in the IMR can be explained indirectly through the causes contributing to excess mortality. The perinatal problems that contributed the most to excess mortality and regional disparities in this study were related to maternal causes such as age, obesity, and smoking, fetal sex and ethnicity, prenatal care, socioeconomic status, and the protocol and capacity of neonatal intensive care units (NICUs).[22-29] According to previous studies, the factors affecting the mortality of children and adolescents in developed countries were divided into 4 domains: intrinsic (biological and psychological) factors, the physical environment, the social environment, and service delivery.[30] Applying this classification to the risk of perinatal mortality, factors related to perinatal problems are mainly related to social environment and service delivery, except for fetal sex, which is classified as an intrinsic factor. Regarding fetal sex, many studies have reported that the perinatal mortality rate of boys is higher than that of girls.[23,29] In Korea, the sex ratio at birth in Seoul is lower than that in other regions, and although recently alleviated, it has been reported that Daegu and Gyeongsangbuk-do, where the preference for sons is strong, have a high sex ratio at birth.[31] In particular, between 2001 and 2021, which was the study period, the sex ratio at birth was high on average in the Gyeongsang province area. Although fetal sex was classified as an intrinsic factor, in a study that analyzed the sex ratio at birth and parents' social status, it was found that since the late 1990s, the higher the parents' social status, the lower the sex ratio at birth. This means that the sex ratio at birth not only acts as a biological factor but is also affected by the social environment.[32] Sidebotham et al.

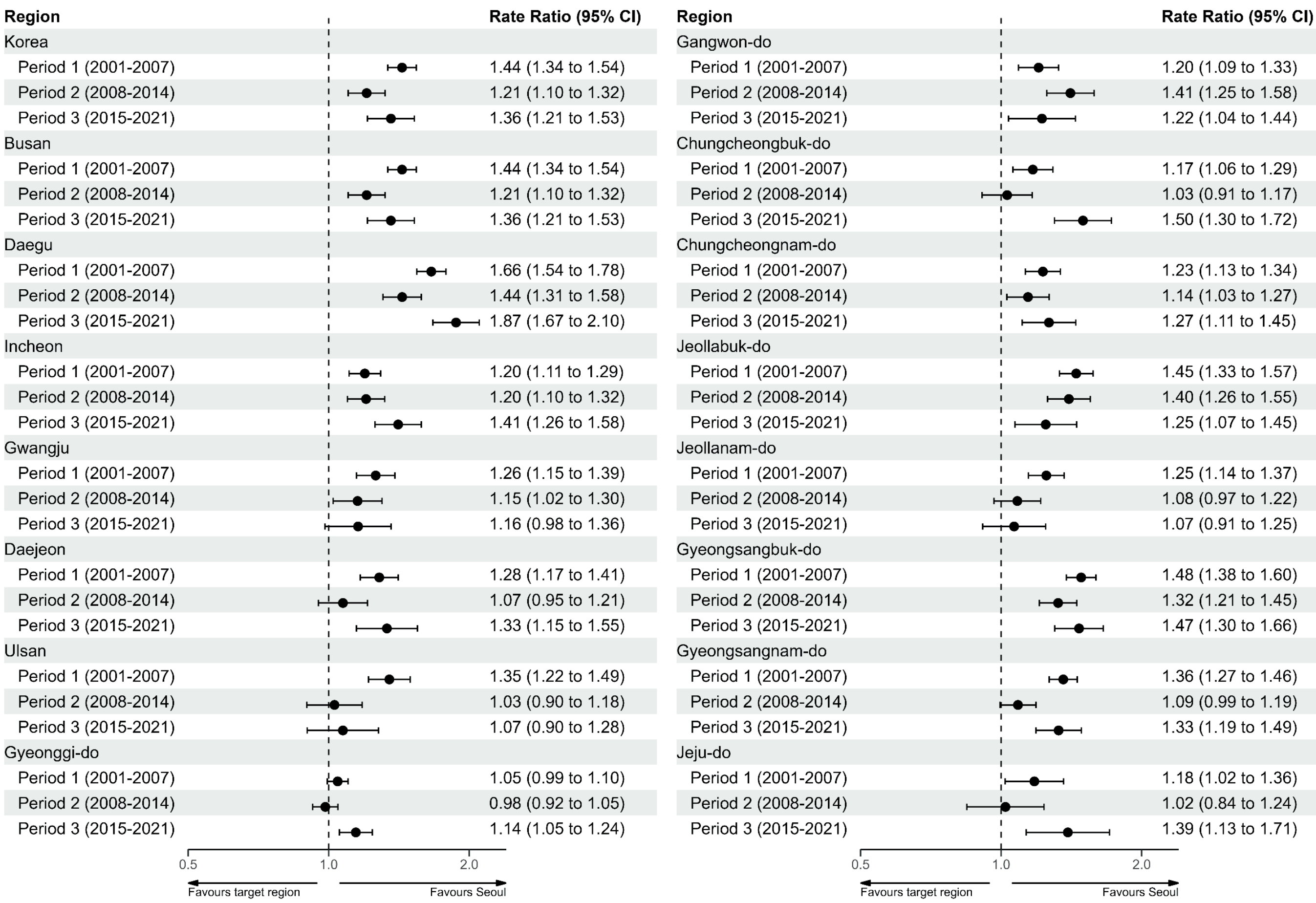

Fig. 4. Trends in the rate ratio of infant mortality by region in Korea.
CI = confidence interval.

reported that the social environment has the greatest effect on child mortality among the 4 domains.[30] Regarding perinatal mortality, social determinants affect maternal pregnancy and postpartum well-being, which in turn will affect perinatal mortality.[26,33,34] A cohort study reported that the regional deprivation index correlated with the IMR in Korea, and metropolitan areas had negative excess mortality and negative deprivation indices compared to local provinces.[35] In a Japanese study that analyzed trends in perinatal mortality, the reduction in perinatal mortality in Japan was largely attributed to the reduction in early neonatal mortality, which was explained by improved NICU capacity, effective interventions to save neonates, and improved quality of treatment.[28] In our study, although the IMR is improving in Korea, there is still a regional gap compared to Seoul, suggesting that service delivery needs to be considered. Due to the nature of healthcare resources, which cannot be stored and are produced and consumed simultaneously, regionalization and risk-appropriate healthcare delivery are important, especially during the perinatal period when transport can be a risk factor that increases mortality.[36] In addition, low accessibility due to physical distance to healthcare centers can contribute to regional disparities. Several studies have reported on the relationship between the distance to healthcare centers and neonatal prognosis.[37-39] Several studies have reported on regional disparities in healthcare resources related to NICUs, and although there have been improvements, regional disparities, particularly in human resources, are still a problem.[16,40,41]

Disparities in the IMR at the regional level have also been studied in other countries.[3-7] In a study comparing IMRs between southern states and states in other regions of the United States, the southern states had a higher IMR than the states in other regions (7.37 vs. 6.19 per 1,000 live births), and the three main causes of excess mortality were sudden unexpected infant death (SUID), prematurity, and congenital anomalies.[3] In another study conducted in the United States, the IMRs were 5.43 per 1,000 live births in large metropolitan areas, 6.31 in medium/small metropolitan areas, and 6.67 in counties in nonmetropolitan areas, and SUID and congenital anomalies were the main causes of excess mortality.[4] Interestingly, in both studies, prematurity, not SUID, was the main cause of excess mortality in black infants, which means that regional disparities cannot simply be generalized and a contextual approach is needed. In most regions in Korea, perinatal problems accounted for the highest proportion of excess deaths, but in some regions, external causes, shock and ill-defined conditions, and congenital anomalies contributed the most to excess mortality. The contribution of external causes to excess mortality was greater in provinces than in metropolitan areas, suggesting the need for an improved physical environment in provinces.

This work has several limitations. First, there have been concerns about the validity of death certificates. Cause of death statistics from the National Statistical Office are based on death certificates and may be inaccurate because of underreporting or misreporting. However, we used infant mortality data after 2001 when underreporting was corrected using cremation data and neonatal death data. In addition, death certificates in Korea are written by a physician, and according to research, the accuracy of the cause of death was relatively accurate at 91.9%.[9,42] Second, our analysis was limited to examining the phenomenon of disparities in IMRs among regions and only presented interpretations post hoc. Further research is needed to analyze the relationship between etiological factors, such as gestational age, birth weight, race, and statuses, and the IMR to understand the mechanism of regional disparities in the IMR and to suggest appropriate policies.

Our study found that the IMR is associated with place of residence, and regional disparities in the IMR have recently widened again. In the context of deepening regional inequality in pediatric-related healthcare resources, especially human resources, these disparities are likely to widen. Therefore, an in-depth investigation of regional disparities in the IMR and policy intervention are urgently needed.

SUPPLEMENTARY MATERIALS

Supplementary Fig. 1

Estimated excess number of deaths attributable to regional disparities and disease distribution for provinces and metropolitan cities (except Seoul) in Korea.

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Supplementary Fig. 2

Trends of infant mortality rates between 2001 and 2021. (**A**) Korea, (**B**) Seoul, (**C**) Busan, (**D**) Daegu, (**E**) Incheon, (**F**) Gwangju, (**G**) Daejeon, (**H**) Ulsan, (**I**) Gyeonggi-do, (**J**) Gangwon-do, (**K**) Chungcheongbuk-do, (**L**) Chungcheongnam-do, (**M**) Jeollabuk-do, (**N**) Jellanam-do, (**O**) Gyeongsangbuk-do, (**P**) Gyeongsangnam-do, (**Q**) Jeju-do.

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Supplementary Fig. 3
Infant mortality rates for Seoul and Korea (**A**) Seoul vs. Korea, (**B**) Seoul vs. Korea (except Seoul).

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Supplementary Fig. 4
Trends in the rate difference of cause-specific infant mortality by region in Korea. (**A**) Perinatal problems, (**B**) congenital anomalies, (**C**) shock and ill-defined conditions, (**D**) injury and external causes, (**E**) circulatory and respiratory problems, (**F**) nervous system problems, (**G**) cancer, blood and immune system problems, (**H**) other causes.

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Supplementary Fig. 5
Trends in the rate ratio of cause-specific infant mortality by region in Korea. (**A**) Perinatal problems, (**B**) congenital anomalies, (**C**) shock and ill-defined conditions, (**D**) injury and external causes, (**E**) circulatory and respiratory problems, (**F**) nervous system problems, (**G**) cancer, blood and immune system problems, (**H**) other causes.

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