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Osong Public Health and Research Perspectives (PHRP) is the international bimonthly (published at the end of February, April, June, August, October, and December) journal founded in 2010 by the Korea Disease Control and Prevention Agency (KDCA). With the mission of the KDCA, to create a disease-free world, PHRP encourages sharing medical information and knowledge in the areas of public health.
PHRP publishes original articles, review articles, guidelines, data profiles (including cohort profiles), special articles, short communications, viewpoints, editorials, commentaries, and correspondence, and book reviews, with a focus on the following areas of expertise: emerging infectious diseases, vaccinology, zoonotic diseases, non-communicable diseases, intractable and rare diseases, and human genomics.

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Editorial

Are we looking at the average or at the distribution? Interpreting divergent signals from the Republic of Korea's national health surveys

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In early December, researchers from academia and frontline public health administrators responsible for the Republic of Korea's 3 flagship health surveys—the Korea National Health and Nutrition Examination Survey (KNHANES), the Community Health Survey (CHS), and the Korea Youth Risk Behavior Survey (KYRBS)—gathered for the first time in nearly 2 decades. This meeting offered a rare opportunity for producers and users of population health data to reflect on what 2 decades of surveillance have revealed, what they have failed to capture, and how future collaboration might better address persistent health disparities across regions and population groups. These inequalities emerged as a central concern. Participants emphasized the need to identify local causal pathways and to develop coordinated strategies integrating ecological perspectives with population-based interventions.

To interpret divergent findings from these surveys, it is essential to recognize their distinct trajectories and design evolutions. KNHANES, initiated in 1998 as a periodic national survey, underwent a major redesign in 2007, becoming a continuous annual survey with standardized field operations and examination protocols. This transition strengthened its role as the Republic of Korea's primary instrument for tracking population means over time.

The CHS was launched in 2007 as an annual survey to support local health governance. With a large, stable sample in every municipality, it provides reliable estimates at the *si/gun/gu* (city/county/district) level, enabling monitoring of regional variation and community-based public health interventions. KYRBS, initiated in 2005 as an annual school-based survey, has served as a core surveillance tool for adolescent health behaviors. It introduced a panel component in 2019, strengthening its capacity to examine longitudinal behavioral patterns and to inform early preventive strategies.

These surveys constitute a maturing national surveillance architecture. Apparent inconsistencies in their findings should be understood not as methodological flaws, but as the result of purpose-built systems operating at different levels of the health system.

KNHANES, in particular, is fundamentally a survey of national means. Examining approximately 10,000 individuals annually and reporting pooled 3-year statistics, it is optimized to track long-term trends in population averages. Because extremes can disproportionately influence the mean, worsening or stagnating national averages are not "noise"; they signal

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that structural risk factors—linked to labor conditions, demographic aging, food environments, and social norms—remain inadequately addressed. KNHANES data have revealed a troubling paradox: average caloric intake has remained largely unchanged, yet the prevalence of obesity and hypercholesterolemia has risen steadily. High-risk alcohol consumption remains widespread, while vigorous physical activity has declined rather than increased [1].

However, averages are blunt instruments. They obscure heterogeneity, dampen local variation, and may remain stable even when interventions produce meaningful changes for many people in specific regions or contexts.

The CHS, by contrast, is designed to detect such changes. With a sample of approximately 230,000 adults across all municipalities, it emphasizes medians and interregional comparisons, making it more sensitive to changes affecting the "typical" community resident. Community-level interventions—such as recreational infrastructure, more walkable environments, and health center–led programs targeting alcohol consumption and physical activity—may therefore be visible in CHS before they influence national means. The 2024 CHS findings, showing lower median levels of high-risk drinking, higher median physical activity, and reduced regional gaps, suggest that such interventions may be beginning to take effect. From a policy perspective, this is encouraging, implying that sustained and adequately resourced local action can influence population health behaviors [2].

Yet this apparent progress must be interpreted with caution. A reduction in disparities does not necessarily indicate improved population health. Regional gaps can narrow because disadvantaged areas improve, but also because previously advantaged areas deteriorate. Mean and median based indicators provide little information about changes in the distribution's spread or about outcomes among the most vulnerable groups. Without examining variance, interquartile ranges, and distributional tails, it is impossible to distinguish genuine equity gains from downward convergence [3].

This tension between national averages and regional medians reflects a well-recognized phenomenon in population health. Geoffrey Rose famously argued that most cases of disease arise not from a small group at extreme risk, but from the large number of people exposed to modest risk [4]. Sustainable improvements therefore require strategies that shift the entire distribution of risk. Such shifts occur gradually and are often first detectable as changes in medians and dispersion, rather than as immediate improvements in the mean [5].

Viewed through this lens, the divergent signals from KNHANES and CHS are not contradictory. They suggest a transitional phase: early community-level distributional changes that are not yet sufficient to alter national averages. CHS may be capturing the initial stages of a population-wide shift driven by local interventions, while KNHANES indicates that these shifts have not reached the scale or intensity required to overcome entrenched structural determinants.

The implications for policy and research are substantial. The central question is no longer which survey is correct, but how insights from different surveillance systems can be integrated. Reliance on means, medians, or simple maximum–minimum gaps alone is inadequate. Instead, analyses must incorporate measures of variance, interquartile ranges, and gradients across social determinants of health, including income, education, occupation, and housing conditions [6].

Moreover, translating community-level improvements into national gains requires action beyond the health sector. Improvements in physical activity and alcohol consumption cannot be sustained through health programs alone; they depend on labor policies shaping working hours, urban planning that enables active transport, housing policies influencing neighborhood environments, and regulatory approaches addressing alcohol availability and marketing. Medical cost subsidies and intensified treatment of high-risk individuals, while important, are insufficient to shift population averages. Equally important, success cannot be declared solely on the basis of improved medians or reduced regional gaps. If disease prevalence continues to rise, convergence of indicators may mask a worsening overall burden. Conversely, improvements in national averages that leave inequalities unchanged are unlikely to be durable. Population health improvement and health equity are inseparable objectives.

Therefore, policymakers, researchers, and practitioners face a challenge: are we content to monitor averages, or are we prepared to confront the full distribution of health and its social determinants?

Notes

Ethics Approval
Not applicable.

Conflicts of Interest
Jong-Koo Lee has been the editor-in-chief of *Osong Public Health and Research Perspectives* since October 2021.

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Review Article

The effects of resistance training on hemoglobin A1c, body mass index, and muscle strength in patients with diabetes mellitus based on age (middle-aged and older adults): a systematic review and meta-analysis

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ABSTRACT

Objectives: This study aimed to examine the effectiveness of resistance training on hemoglobin A1c (HbA1c) levels and body mass index in patients with diabetes mellitus, categorized by age.
Methods: A comprehensive search of English-language literature published between 1997 and 2025 was performed across 6 databases (Embase, CINAHL, Medline, Cochrane, PubMed, and PEDro). Standardized mean differences and 95% confidence intervals were calculated, and publication bias was assessed using funnel plots and Egger's test. The Joanna Briggs Institute checklist was applied to evaluate study quality.
Results: Thirty randomized controlled trials met the inclusion criteria, comprising 620 participants in the older (< 60 years of age) subgroup and 1,389 in the middle-aged (40–59 years of age) subgroup. In both subgroups, resistance training significantly reduced HbA1c levels and body mass index, while increasing muscle strength (primary outcome). It also significantly increased high-density lipoprotein, improved VO_2 peak, and reduced low-density lipoprotein (secondary outcomes). However, the effects of resistance training were significant only in the older-adult subgroup for total cholesterol and only in the middle-aged subgroup for triglycerides.
Conclusion: Resistance training is a recommended rehabilitation exercise for patients with diabetes mellitus. Routine resistance training has been shown to help maintain optimal HbA1c and body mass index levels and improve muscle strength. In addition, it does not pose a risk of adverse events in either middle-aged or older patients. Nonetheless, patients are advised to monitor blood glucose levels and adhere to a proper diet to achieve optimal outcomes.

Keywords: Body mass index; Diabetes mellitus; Hemoglobin A1c; Muscle strength; Resistance training

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Introduction

Diabetes mellitus (DM) is a global health problem caused by a chronic metabolic disorder characterized by elevated blood glucose (hyperglycemia) due to impaired insulin secretion [1,2]. Several complications of chronic hyperglycemia include elevated hemoglobin A1c (HbA1c) levels, increased body mass index (BMI), and reduced muscle strength (MS). These factors strongly influence quality of life, rehospitalization rates, and mortality in patients with DM [1]. Hyperglycemia also contributes to dyslipidemia, which increases the risk of atherosclerosis and cardiovascular disease [2,3]. Therefore, appropriate evidence-based interventions are urgently needed to address these issues.

Several strategies have been developed to optimize outcomes in patients with DM. Alongside standard medical therapy, resistance training (RT) is one such approach [4,5]. The American College of Sports Medicine recommends incorporating RT into rehabilitation programs for patients with DM in addition to pharmacological treatment [6]. Studies consistently demonstrate that RT improves glycemic control and insulin sensitivity [7,8], as well as lipid abnormalities in individuals with DM [9]. Previous research has also shown that RT exerts favorable effects in reducing HbA1c [8] and BMI [10,11]. Moreover, RT is hypothesized to help stabilize lipid profiles in patients with DM [9]. However, aging is associated with reduced insulin sensitivity, muscle loss (sarcopenia), weight gain (obesity) [12], and a more rapid decline in physiological function compared with younger individuals. These age-related factors may attenuate the beneficial effects of RT in individuals with diabetes.

Aging is also associated with declines in multiple organ functions [13]. In particular, older adults experience greater difficulty addressing muscle-related deficits through exercise regimens, partly because of impaired post-exercise muscle protein synthesis due to anabolic resistance [14]. Consequently, improvements in muscle mass among older patients with DM may be limited. In addition, the effects of RT on HbA1c, muscle mass, and glucose metabolism in older patients with DM are often less pronounced than in younger individuals. Previous studies have reported that RT did not significantly reduce HbA1c [10] or BMI in older patients [15]. Furthermore, RT showed no significant effect on upper-limb MS in this population [16]. Between 2016 and 2025, 6 meta-analyses examined RT in patients with DM [17–22], yet none specifically assessed its effects on HbA1c, BMI, and MS across different age groups. This gap is important, as diabetes complications vary with age. Accordingly, evaluating the effects of RT on HbA1c, BMI, and MS (both lower and upper limbs) in patients with DM by age group—including middle-aged and older adults—is essential. This study also provides insights into rehabilitation strategies for diabetes, offering practical implications for patients, families, and healthcare providers. The primary objective of this review was to compare the effectiveness of RT on HbA1c, BMI, and MS between middle-aged and older patients. Secondary outcomes included the effects of RT on VO_2 peak, lipid profiles (cholesterol, triglycerides, high-density lipoprotein [HDL], and low-density lipoprotein [LDL]), and the occurrence of serious adverse events in patients with DM.

HIGHLIGHTS

- Resistance training is one of the rehabilitation recommendations for patients with diabetes mellitus.
- Regular resistance training helps maintain better hemoglobin A1c levels and body mass index in middle-aged and older adults with diabetes mellitus.
- Routine resistance training increases muscle strength in middle-aged or older adults with diabetes mellitus.
- Resistance training does not cause serious adverse events in middle-aged or older adults with diabetes mellitus.

Materials and Methods

Data Sources and Systematic Literature Review

This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Figure 1). Six databases—Embase, CINAHL, Medline, Cochrane, PubMed, and PEDro—were searched, and results were organized using the PICO framework. The population (P) included individuals with DM. The intervention (I) comprised RT alone or RT combined with aerobic exercise, vitamin D, or endurance training. The comparison (C) was standard care, and the outcomes (O) were HbA1c, BMI, and MS. The search strategy used Emtree/Medical Subject Headings (MeSH) terms and relevant keywords, including diabetes, diabetic, nonspecific DM, resistance exercise, resistance training, strength training, weight-bearing exercise, glycated hemoglobin A1c, glycosylated hemoglobin A1c, hemoglobin A1c, HbA1c, body mass index, Quetelet index, muscle strength, muscle force, muscle power, and dynamic muscular strength. This review was registered with PROSPERO (CRD420251063715).

This review included only English-language randomized

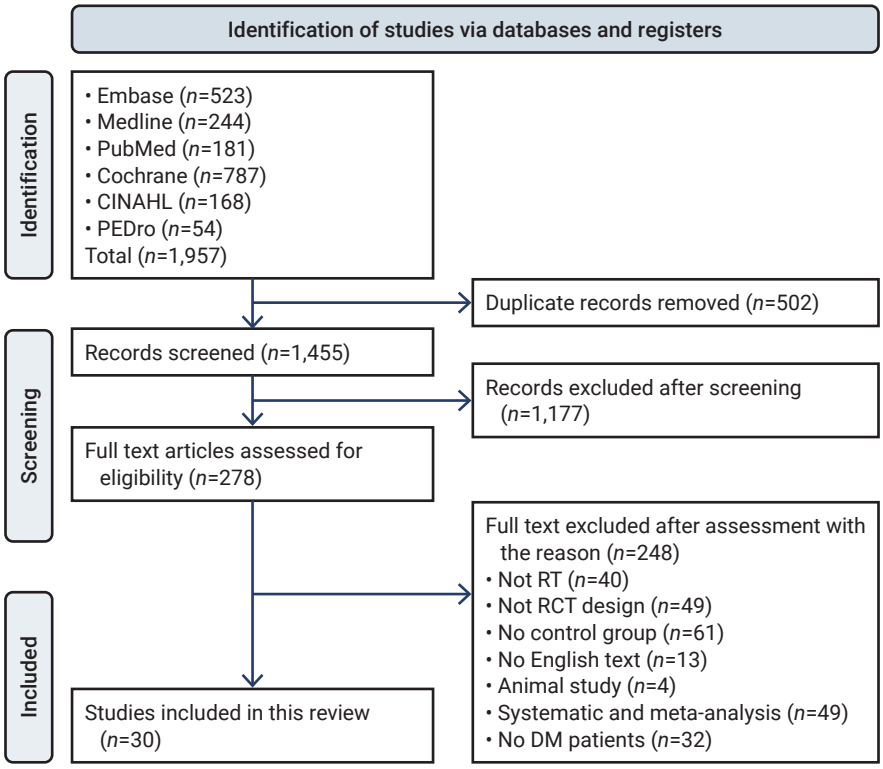


Figure 1. Flow diagram of the study selection process.
RT, resistance training; RCT, randomized controlled trial; DM, diabetes mellitus.

controlled trials (RCTs) published between 1997 and 2025 that examined RT (alone or in combination with aerobic, vitamin D, or endurance training) in patients with DM. The search was conducted from April to June 2025. Exclusion criteria included systematic reviews or meta-analyses, RCTs without a control group, animal studies, studies not involving DM patients, and studies unrelated to HbA1c, BMI, or MS. After identification, duplicate articles were carefully removed. Screening involved abstract and title review, followed by full-text evaluation and reference list checks. The process concluded when all authors reviewed the reference lists of the included full texts and confirmed that no additional eligible studies were found.

Extracting Data and Assessment Quality of the Studies

All reviewers independently extracted data on study design, participant age (middle-aged: 40–59 years; older: ≥60 years), type of DM, intervention characteristics (RT type, frequency, and duration), and reported outcomes, as summarized in Table 1 [7,9–11,15,16,23–46]. Study quality was independently assessed by all reviewers using the Joanna Briggs Institute (JBI) checklist (Table 1). Publication bias was evaluated using the Egger test.

Statistical Analysis and Data Synthesis

Data synthesis was performed using RevMan 5.4 software (Cochrane). Baseline-to-follow-up changes were analyzed to assess intervention effects. Standardized mean differences (SMDs) and risk differences (RDs) were calculated, with 95% confidence intervals (CIs) used to determine statistical significance. Primary outcomes included HbA1c, BMI, and MS. Secondary outcomes included lipid profiles (cholesterol, HDL, LDL, triglycerides), VO_2 peak, and serious adverse events. Effect sizes were reported for both primary and secondary outcomes. Results from individual studies and the pooled meta-analysis were presented in forest plots. Study heterogeneity was evaluated using the I^2 statistic. A random-effects model was applied when heterogeneity exceeded 50%, while a fixed-effects model was used when heterogeneity was below 50%.

Risk of Bias Assessment

Each study's risk of bias was independently assessed by reviewers using the Cochrane Handbook for Systematic Reviews of Interventions criteria and the RoB 2 tool. Disagreements were resolved through discussion. Bias risk was categorized as high, low, or unclear, with justifications provided in a risk of bias summary and risk of bias graph

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Table 1. Characteristics of the studies

No.	Study	Year	Age (y, mean ± SD)	E/C	Type of DM	Components of RT			Control	Outcome	JBI score
						Type of intervention	FE (time/wk)	DE (wk)			
1	Bacchi et al. [23]	2012	55.6 ± 1.7	19/19	II	Exercise using weight machines. Each session consists of 9 exercises. The workload was progressively increased to 70% to 80% of 1-RM after 10 repetitions at 30% to 50% of 1-RM on each piece of equipment.	3	12	Aerobic	HbA1c, MS, BP, serious events	10/13
2	Bassi et al. [11]	2015	52.1 ± 7.3	21/20	II	Aerobic+RT, Exercise lasted one hour and 10 minutes and comprised a 5-minute warm-up, a 60-minute workout, and a 5-minute cool-down.	3	12	Aerobic	HbA1c, BMI, VO_2 peak, MS, BP	12/13
3	Banitalebi et al. [24]	2019	54.14 ± 5.43	14/14	II	5 Minutes warm-up (cycling or treadmill), 10 minutes cool-down (cycling/ treadmill), main exercise: aerobic+RT (weight stack machines) for 5 exercises (bilateral leg press, lateral pull down, bench press, bilateral biceps curl, and bilateral triceps push down)	3	10	Usual care	HbA1c, BMI, VO_2 peak	13/13
4	Cauza et al. [25]	2005	56.4 ± 1.1	22/17	II	10 Minutes warm-up; RT exercise: Bench press, chest cross, shoulder press, pull-downs, biceps curls, triceps extensions, and abdominal exercises were among the upper-body strengthening exercises. Leg extensions, calf lifts, and leg presses were among the lower-body workouts.	3	12	Endurance training	HbA1c. BMI, MS, BP	8/13
5	Celli et al. [26]	2022	72.3 ± 4.0	50/50	II	15 Minutes warm-up, 30 minutes aerobic+30 minutes RT consisted of 9 upper-body and lower-body exercises (weight lifting machines), 15 minutes balance exercise	-	16	Usual care	HbA1c, BMI, VO_2 peak, serious events	11/13
6	Cheung et al. [27]	2009	59 ± 8.7	20/17	II	5 Minutes warm-up, 30 minutes RT (chest press, seated back rows, leg abductions, leg extension, seated leg press, triceps extensions, and biceps curls)	5	-	Usual care	HbA1c, BMI, MS	7/13

(Continued on the next page)

Table 1. Continued

No.	Study	Year	Age (y, mean ± SD)	E/C	Type of DM	Components of RT			Control	Outcome	JBI score
						Type of intervention	FE (time/wk)	DE (wk)			
7	Chien et al. [28]	2022	67.6 ± 7.7	19/18	II	The RT equipment used was sandbags. 5 to 10 minutes for warm-up/cool-down. The RT included tiptoe (ankle flexion/extension), hip adduction/abduction, overhead press (shoulder), arm curl (elbow flexion/extension), and step (hip and knee flexion/extension).	-	-	Usual care	MS, HbA1c	12/13
8	Church et al. [29]	2010a	56.9 ± 8.7	73/41	II	RT comprising 2 sets of 4 upper-body exercises (bench press, seated row, shoulder press, and pull down), 3 sets of 3 leg exercises (leg press, extension, and flexion), and 2 sets each of abdominal crunches and back extensions.	3	36	Usual care	MS	9/13
9	Church et al. [29]	2010b	55.4 ± 8.3	76/41	II	Aerobic+RT comprising 2 sets of 4 upper-body exercises (bench press, seated row, shoulder press, and pull down), 3 sets of 3 leg exercises (leg press, extension, and flexion), and 2 sets each of abdominal crunches and back extensions.	3	36	Usual care	MS	9/13
10	Hameed et al. [30]	2012	44.7 ± 4.2	24/24	II	Weight machines (bench press, leg press, lateral pull, leg extension, seated biceps curls)	2–3	8	Cycling	MS, HbA1c, BP	9/13
11	Hangping et al. [31]	2019	65.66 ± 8.58	59/32	II	RT; 4 exercises (chess press, leg press, core pull and vertical lift)	1	24	Usual care	HbA1c, HDL, LDL, serious events	12/13/
12	Honkola et al. [32]	1997	62 ± 2	18/20	II	Progressive circuit-type RT	3	20	Usual care	HbA1c, HDL, LDL, cholesterol, triglyceride, BP	8/13
13	Hsieh et al. [16]	2018	70.6 ± 4.2	15/15	II	RT used weight machine (chest press, shoulder press, biceps curl, hip abduction, standing hip flexion, leg press, standing calf raise, and abdominal crunch)	3	12	Aerobic	HbA1c, MS, VO_2 peak, BP	10/13
14	Kang et al. [33]	2016	56 ± 7.4	8/8	II	10 Minutes (warm-up/cooling down), aerobic+resistance exercise using weight machines (chest press, lateral pull down, shoulder press, arm curl, leg press, leg extension, leg curl, calf raise, and curl-up)	3	12	Usual care	HbA1c, HDL, LDL, cholesterol, triglyceride, BP	8/13

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Table 1. Continued

No.	Study	Year	Age (y, mean ± SD)	E/C	Type of DM	Components of RT			Control	Outcome	JBI score
						Type of intervention	FE (time/wk)	DE (wk)			
15	Khan et al. [15]	2022a	62 ± 9	15/15	II	10 Bicycle ergometry, progressive RT (upper, and lower body)	2–3 Sessions/wk	12	Usual care	HbA1c, BMI, MS, serious events	13/13
16	Khan et al. [15]	2022b	63 ± 8	13/17	II	10 Bicycle ergometry, progressive RT (upper, and lower body)	2–3 Sessions/wk	12	Usual care	HbA1c, BMI, MS, serious events	13/13
17	Kobayashi et al. [7]	2023a	60 ± 53.66	38/38	II	RT used weight machines (bench press, seated row, shoulder press and pull down, leg press/extension/flexion, abdominal crunches and back extensions)	3	12	Aerobic	HbA1c, MS, serious events	13/13
18	Kobayashi et al. [7]	2023b	59 ± 52.68	31/38	II	Aerobic+treadmill and RT used weight machines (bench press, seated row, shoulder press and pull down, leg press/extension/flexion, abdominal crunches and back extensions)	3	12	Aerobic	HbA1c, MS, serious events	13/13
19	Ku et al. [34]	2010	55.7 ± 6.2	13/16	II	RT using elastic band (biceps curl, triceps extension, upright row, shoulder chest press, trunk side-bending, seated row, leg press, hip flexion, leg flexion and leg extension)	5	12	Usual care	HbA1c, BMI, MS	6/13
20	Lambers et al. [35]	2008a	55.8 ± 9.66	17/11	II	10 Minutes warm-up/cool-down, ST (weight machines)+walking, cycling, knee flexion/extension, stepping	-	12	Usual care	HbA1c, BMI, MS	12/13
21	Lambers et al. [35]	2008b	52.2 ± 8.26	18/11	II	10 Minutes warm-up/cool-down, ST (weight machines)+walking, cycling, knee flexion/extension, stepping, and endurance training (treadmills, stationary bicycles and steppers)	-	12	Usual care	HbA1c, BMI, MS	12/13
22	Liu et al. [36]	2015	52.9 ± 11.43	22/20	II	10 Minutes warm-up, 15 minutes cool-down, aerobic+RT (elastic band)	2–3	12	Usual care	HbA1c, HDL, LDL, cholesterol, triglyceride	10/13
23	Loimaala et al. [37]	2009	53.6 ± 6.2	24/24	II	Aerobic+RT (weight machines)	2	8	Usual care	HbA1c, MS, VO_2 peak, BP	11/13
24	Magalhaes et al. [38]	2019a	59.7 ± 6.5	28/27	II	Moderate intensity+RT	-	48	Usual care	HbA1c, BMI, VO_2 peak	13/13

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Table 1. Continued

No.	Study	Year	Age (y, mean ± SD)	E/C	Type of DM	Components of RT			Control	Outcome	JBI score
						Type of intervention	FE (time/wk)	DE (wk)			
25	Magalhaes et al. [38]	2019b	56.7 ± 8.3	25/27	II	High intensity+RT	-	48	Usual care	HbA1c, BMI, VO_2 peak	13/13
26	Mavros et al. [39]	2013	-	36/48	II	Progressive resistance training: concentric contraction (lifting), and eccentric contraction (lowering); workouts aimed at substantial symmetrical muscle groups of the arms, legs, and torso: seated row, chest press, leg press, knee extension, hip flexion, hip extension, and hip abduction.	3	16	Sham	HbA1c, BMI	10/13
27	Plotnikoff et al. [40]	2010	55 ± 12	27/21	II	Weight machines (multigym and dumbbells)	3	16	Usual care	MS, BMI, HbA1c, serious events	12/13
28	Rech et al. [41]	2019	70.5 ± 7.4	18/21	II	RT program comprised functional exercises like partial squats and bench stepping, while traditional resistance exercises encompassed the unilateral leg press, unilateral knee extension, knee flexion, plantar flexion, bench press, low row, biceps curl, elbow extension, hip abduction, and abdominal crunches.	3	12	Usual care	HbA1c, cholesterol, triglyceride, HDL, LDL	13/13
29	Sigal et al. [42]	2007a	53.5 ± 7.3	64/63	II	Aerobic+RT (weight machine)	3	24	Usual care	HbA1c, BMI, cholesterol, triglyceride, HDL, LDL, BP, serious events	13/13
30	Sigal et al. [42]	2007b	54.7 ± 7.5	64/63	II	RT (weight machine)	3	24	Usual care	HbA1c, BMI, cholesterol, triglyceride, HDL, LDL, BP, serious events	13/13
31	Stubbs et al. [44]	2019a	64.2 ± 9.5	11/12	II	10 Minutes warm-up, 10 minutes cool, RT (isokinetic strength)	-	24	Usual care	HbA1c, BMI. VO_2 peak	13/13
32	Stubbs et al. [44]	2019b	63 ± 6.6	11/12	II	10 Minutes warm-up, 10 minutes cool-down, aerobic+RT (isokinetic strength)	-	24	Usual care	HbA1c, BMI, VO_2 peak	13/13
33	Sudarsono et al. [43]	2019	51.69 ± 7.7	22/20	II	RT (weight machine)		12	Usual care	HbA1c	12/13
34	Sun et al. [9]	2023a	50.1 ± 7.3	15/15	II	RT (endurance cycling exercise)	-	12	Usual care	HbA1c, BMI, cholesterol, triglyceride, HDL, LDL	13/13

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Table 1. Continued

No.	Study	Year	Age (y, mean ± SD)	E/C	Type of DM	Components of RT			Control	Outcome	JBI score
						Type of intervention	FE (time/wk)	DE (wk)			
35	Sun et al. [9]	2023b	50.1 ± 7.3	14/15	II	Vit D+RT (endurance cycling exercise)	-	12	Usual care	HbA1c, BMI, cholesterol, triglyceride, HDL, LDL	13/13
36	Tan et al. [45]	2012	65.9 ± 4.2	15/10	II	10 Minutes warm-up, 10 minutes cool-down, 30 minutes walking, 10 minutes RT (weight machine)	3	24	Usual care	HbA1c, BMI, VO_2 peak, cholesterol, triglyceride, HDL, LDL, BP	9/13
37	Yavari et al. [46]	2012a	51.5 ± 6.3	20/20	II	Weight machine (bench press, seated row, shoulder press, chest press, lateral pulldown, abdominal crunches, leg press, leg extension, triceps pushdown and seated bicep curls)	3	52	Usual care	HbA1c, BMI, cholesterol, triglyceride, HDL, LDL, BP	8/13
38	Yavari et al. [46]	2012b	50.9 ± 9.8	20/20	II	Aerobic+weight machine (bench press, seated row, shoulder press, chest press, lateral pulldown, abdominal crunches, leg press, leg extension, triceps pushdown and seated bicep curls)	3	52	Usual care	HbA1c, BMI, cholesterol, triglyceride, HDL, LDL, BP	8/13
39	Yamamoto et al. [10]	2021a	73.2 ± 2.6	18/17	II	RT used an elastic band	7	48	Usual care	MS, BMI, HbA1c	12/13
40	Yamamoto et al. [10]	2021b	72.1 ± 2.1	18/17	II	RT used an elastic band+leucine-rich supplement	7	48	Usual care	MS, BMI, HbA1c	12/13

SD, standard deviation; E/C, experiment/control; DM, diabetes mellitus; RT, resistance training; FE, frequency of exercise; DE, duration of exercise; JBI, Joanna Briggs Institute; RM, repetition maximum; HbA1c, hemoglobin A1c; MS, muscle strength; BP, blood pressure; BMI, body mass index; HDL, high-density lipoprotein; LDL, low-density lipoprotein; ST, strength training; -, not reported.

(Figure S1). Publication bias was also assessed using funnel plots (Figure S2).

Results

Study Description

The preliminary screening identified 1,957 studies from 6 databases: Embase (n=523), Medline (n=244), Cochrane (n=787), CINAHL (n=168), PubMed (n=181), and PEDro (n=54). Of these, 502 duplicates were removed, and 1,177 articles were excluded after title and abstract review. A total of 278 articles underwent full-text screening, but 248 were excluded for the following reasons: not RT studies (n=40), not RCT designs (n=40), absence of a control group (n=61), non-English language (n=13), review articles (systematic or meta-analyses) (n=49), animal studies (n=4), and outcomes unrelated to DM patients (n=30). Ultimately, 30 articles [7,9–11,15,16,23–46] met the inclusion criteria (Figure 1).

Characteristics of the Studies

Thirty RCTs published between 1997 and 2025 were included, comprising 620 older and 1,389 middle-aged participants with diagnosed DM. Participant mean ages ranged from 44.7±4.2 to 73.2±2.6 years. Among older participants, 316 were assigned to intervention groups and 304 to control groups. Among middle-aged participants, 739 were assigned to intervention groups and 650 to control groups. Study quality, assessed with the JBI checklist, ranged from 6 to 13 out of the maximum score (Table 1).

Table 1 provides a detailed overview of RT components across studies. Twenty-one studies used weight machines to deliver RT, while others employed elastic bands, progressive resistance programs, sandbag exercises, or isokinetic strength and endurance training. Training frequency ranged from 1 to 7 sessions per week, and intervention duration varied from 8 to 54 weeks. Many studies also incorporated structured warm-up and cool-down periods. Typically, these included a 5- to 10-minute warm-up before the main RT session, followed by a cool-down phase.

Methodological Quality and Potential for Bias

The methodological quality of included studies, as assessed by the JBI checklist, was moderate to high following consensus by the 3 reviewers (Table 1). Approximately 50% of studies demonstrated a low risk of bias in random sequence generation, and allocation concealment was satisfactory in over 60% of studies. Around 70% reported a low risk of bias in outcome assessment blinding. More than 75% showed a low risk of selective reporting and incomplete outcome data. However, fewer than 60% reported a low risk of bias regarding participant and personnel blinding (Figure S1). Evidence of potential publication bias was observed, as indicated by funnel plots. Heterogeneity was primarily attributable to the presence of 2 distinct study subgroups, particularly regarding the effects of RT on HbA1c, BMI, and MS (Figure S2).

Effect of RT on HbA1c, BMI, and MS in Patients with DM (Primary Outcome)

Effect of RT on HbA1c

Table 2 and Figure 2 summarize 15 trials including 699 participants in the older-adult subgroup. These analyses showed that RT significantly reduced HbA1c in the intervention group (SMD, −0.88; 95% CI, −1.66 to −0.10; I^2=95%) compared with the control group. Similarly, 27 studies involving 1,457 middle-aged participants demonstrated that RT significantly reduced HbA1c in the intervention group (SMD, −0.86; 95% CI, −1.26 to −0.45; I^2=92%) relative to the control group.

Effect of RT on BMI

Nine studies in the older-adult subgroup, with 182 participants in intervention groups and 192 in control groups, indicated that RT significantly reduced BMI among patients with DM (SMD, −1.21; 95% CI, −2.39 to −0.04; I^2=96%) compared to controls. Sixteen studies in the middle-aged subgroup, comprising 260 intervention participants and 251 controls, also showed a significant BMI reduction in intervention groups (SMD, −0.36; 95% CI, −0.63 to −0.10; I^2=53%). These findings are presented in Table 2 and Figure 3.

Effect of RT on MS

As shown in Figure 4 and Table 2, 7 RCTs with 242 older participants revealed that RT significantly improved lower-limb MS in the intervention group (SMD, 0.79; 95% CI, 0.44 to 1.14; I^2=40%) compared with controls. Likewise, eleven studies involving 414 middle-aged participants demonstrated significant improvements in lower-limb MS in the intervention group (SMD, 1.54; 95% CI, 0.81 to 2.28, I^2=90%).

RT also significantly improved upper-limb MS. In older participants, intervention groups showed an improvement (SMD, 0.37; 95% CI, 0.03 to 0.71; I^2=0%) compared to controls. In middle-aged participants, RT similarly improved upper-limb MS (SMD, 0.91; 95% CI, 0.38 to 1.44; I^2=80%) compared to control groups (Figure 5; Table 2).

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Table 2. Summarized results for the intervention versus control

Outcome	No. of studies	No. of respondents	Methods	ES	Overall effect Z (*p*)
Primary outcomes					
HbA1c (total)					
Elderly	15	699	SMD (IV, R, 95% CI)	−0.88 (−1.66, −0.10)	2.20 (0.03)
Middle age	27	1,457	SMD (IV, R, 95% CI)	−0.86 (−1.26, −0.45)	4.16 (<0.00001)
BMI (total)					
Elderly	9	374	SMD (IV, R, 95% CI)	−1.21 (−2.39, −0.04)	2.02 (0.04)
Middle age	15	511	SMD (IV, R, 95% CI)	−0.36 (−0.63, −0.10)	2.72 (0.006)
MS (lower limbs) (total)					
Elderly	7	242	SMD (IV, R, 95% CI)	0.79 (0.44, 1.14)	4.46 (<0.00001)
Middle age	11	414	SMD (IV, R, 95% CI)	1.54 (0.81, 2,28)	4.14 (<0.00001)
MS (upper limbs) (total)					
Elderly	4	137	SMD (IV, R, 95% CI)	0.37 (0.03, 0.71)	2.15 (0.03)
Middle age	9	351	SMD (IV, R, 95% CI)	0.91 (0.38, 1.44)	3.35 (0.0008)
Secondary outcomes					
Cholesterol (total)					
Elderly	4	132	SDM (IV, R, 95% CI)	−0.94 (−1.62, −0.26)	2.72 (0.006)
Middle age	15	701	SDM (IV, R, 95% CI)	−0.16 (−0.45, 0.14)	1.01 (0.31)
Triglyceride (total)					
Elderly	6	207	SDM (IV, R, 95% CI)	0.41 (−0.92, 1.74)	0.60 (0.55)
Middle age	14	654	SDM (IV, R, 95% CI)	−0.37 (−0.59, −0.14)	3.24 (0.001)
HDL (total)					
Elderly	5	169	SDM (IV, R, 95% CI)	0.40 (−0.01, 0.80)	1.93(0.05)
Middle age	12	583	SDM (IV, R, 95% CI)	0.33 (0.05, 0.61)	2.28 (0.02)
LDL (total)					
Elderly	5	130	SDM (IV, R, 95% CI)	−0.98 (−1.76, −0.21)	2.48 (0.01)
Middle age	10	537	SDM (IV, R, 95% CI)	0.18 (0.01, 0.35)	2.06 (0.04)
VO_2 peak (total)					
Elderly	5	201	SDM (IV, R, 95% CI)	2.80 (0.17, 5.43)	2.08 (0.04)
Middle age	5	188	SDM (IV, R, 95% CI)	1.21 (0.72, 1.71)	4.79 (0.00001)
Serious events					
Elderly	6	423	RD (M-H, F, 95% CI)	0.04 (0.01, 0.10)	1.52 (0.13)
Middle age	4	280	RD (M-H, F, 95% CI)	−0.01 (−0.07, 0.05)	0.28 (0.78)

ES, effect size; HbA1c, hemoglobin A1c; SMD, standard mean difference; IV, inverse variance; R, random; CI, confidence interval; BMI, body mass index; MS, muscle strength; HDL, high-density lipoprotein; LDL, low-density lipoprotein; RD, risk difference; M-H, Mantel-Haenszel; F, fixed.

Effect of RT on Lipid Profiles, VO_2 Peak, and Serious Events in Patients with DM (Secondary Outcome)

Effect of RT on lipid profiles

Lipid profile outcomes are presented in Table 2 and Figures S3–S6. Among older participants, RT significantly reduced total cholesterol (SMD, −0.94; 95% CI, −1.62 to −0.26; I^2 = 70%; n = 132) and LDL (SMD, −0.98; 95% CI, −1.76 to −0.21; I^2 = 76%; n = 130), and significantly increased HDL (SMD, 0.40; 95% CI, −0.01 to 0.80; I^2 = 40%; n = 169). However, RT did not significantly reduce triglycerides (SMD, 0.41; 95% CI, −0.92 to 1.74; I^2 = 94%; n = 207). For middle-aged participants, RT significantly reduced triglycerides (SMD, −0.37; 95% CI, −0.59 to −0.14; I^2 = 43%; n = 654) and LDL (SMD, 0.18; 95% CI, 0.01 to 0.35; I^2 = 0%; n = 537), while also increasing HDL (SMD, 0.33; 95% CI, 0.05 to 0.61; I^2 = 54%; n = 583). However, RT did not significantly reduce total cholesterol (SMD, −0.16; 95% CI, −0.45 to 0.14; I^2 = 70%; n = 701).

Effect of RT on VO_2 peak

Five studies in the older-adult subgroup, including 102 intervention participants and 99 controls, demonstrated that RT significantly improved VO_2 peak compared to controls (SMD, 2.80; 95% CI, 0.17 to 5.43; I^2 = 98%). Similarly, 5 studies with 97 intervention participants and 91 controls in the middle-aged subgroup showed that RT significantly increased VO_2 peak (SMD, 1.21; 95% CI, 0.72 to 1.71; I^2 = 59%). These results are shown in Table 2 and Figure S7.

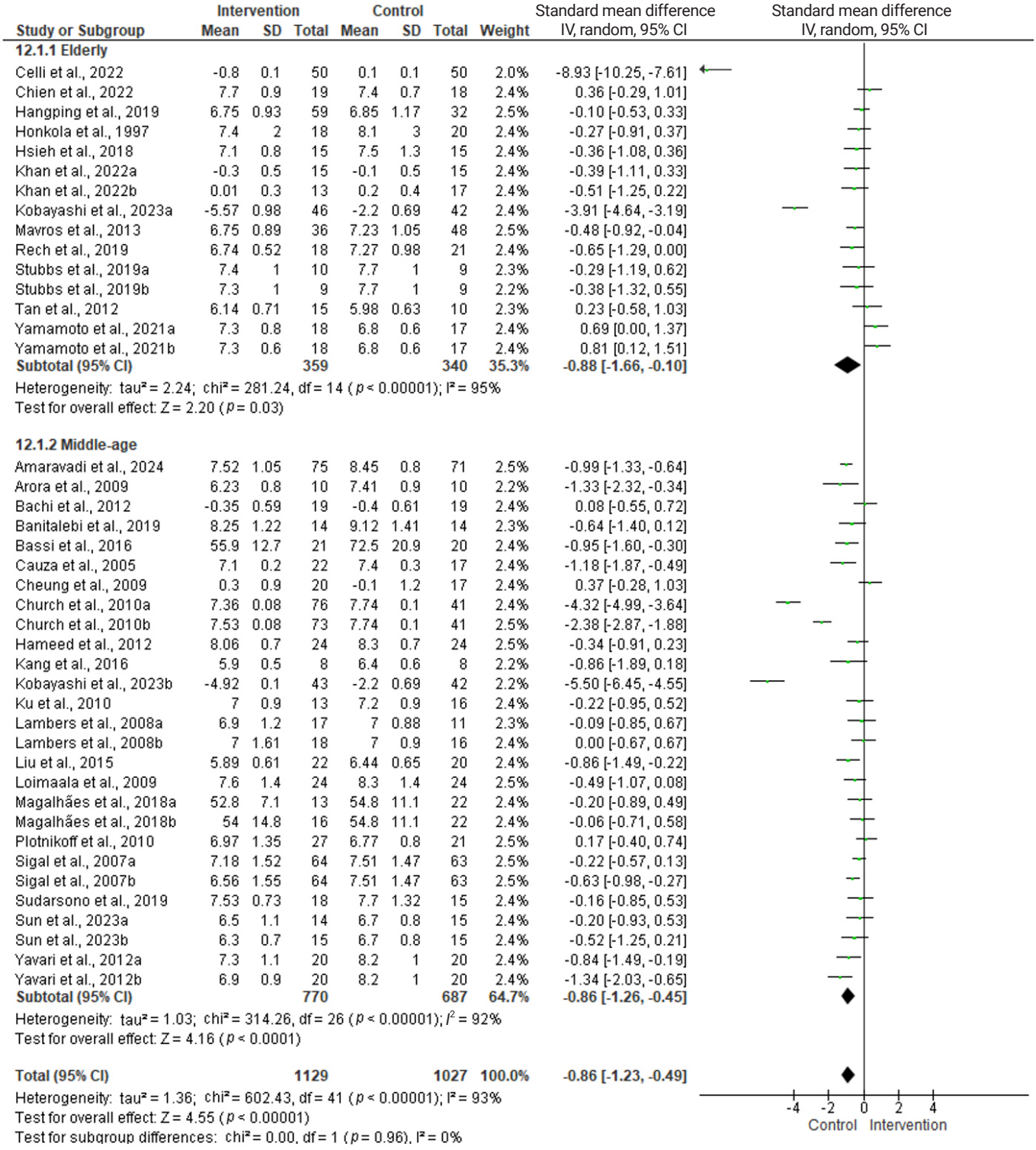


Figure 2. Effect of resistance training on hemoglobin A1c.
SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

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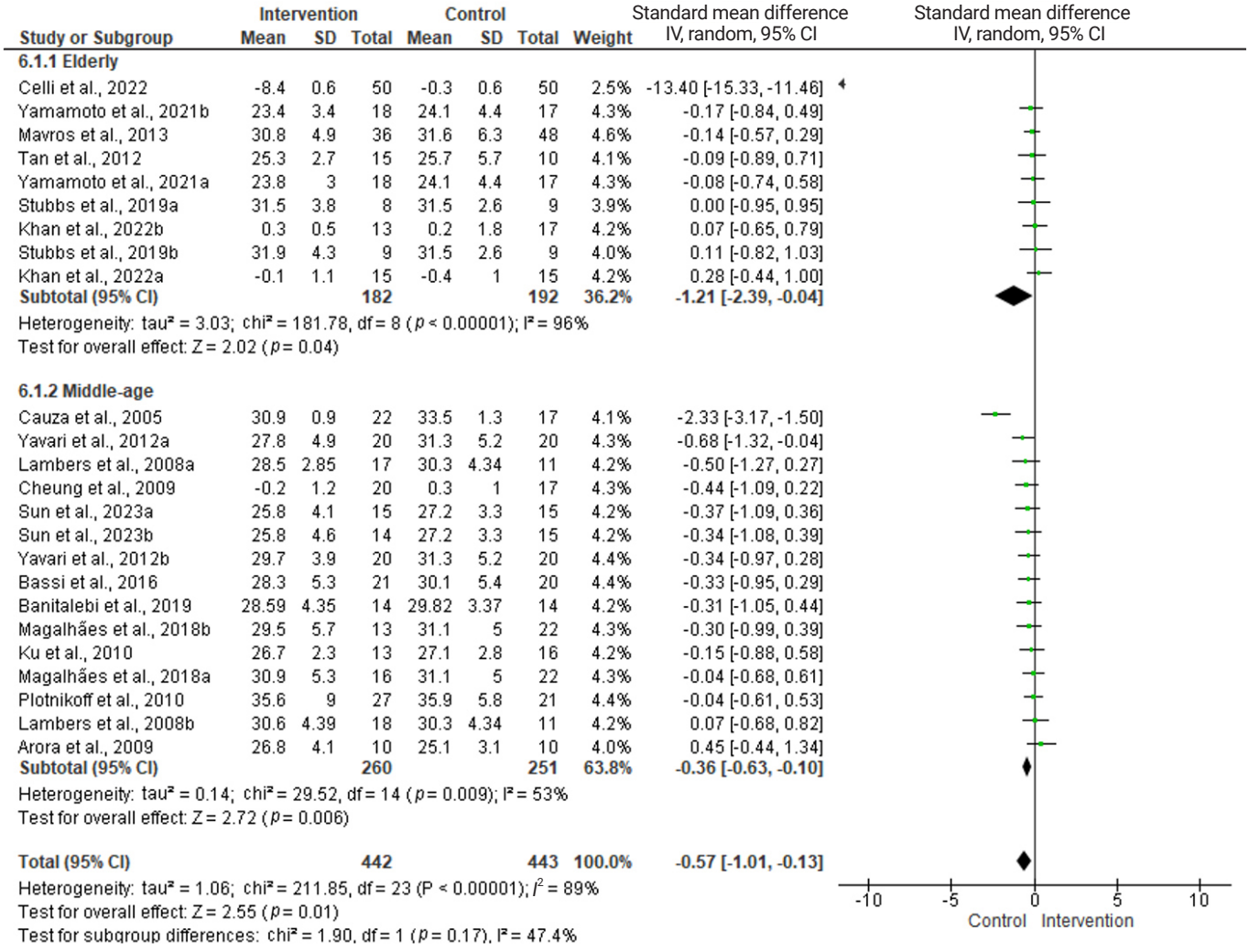


Figure 3. Effect of resistance training on body mass index.
SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

Effect of RT on serious events

In older patients with DM, 423 participants were evaluated (224 in intervention groups and 199 in control groups). RT did not significantly influence the occurrence of adverse events (RD, 0.04; 95% CI, −0.01 to 0.10; I^2 = 52%). Similarly, in middle-aged patients with DM (n = 280; 146 intervention, 134 control), RT showed no significant effect on adverse events (RD, −0.01; 95% CI, −0.07 to 0.05; I^2 = 0%). These findings are presented in Table 2 and Figure S8.

Discussion

This study evaluated the effects of RT on HbA1c, BMI, and MS in patients with DM by comparing intervention and control groups (primary outcomes). The analysis also examined secondary outcomes, including lipid profile, VO_2 peak, and adverse events, in both middle-aged and older-adult subgroups. Overall, the evidence quality of the included studies was assessed as moderate to high (Table 1).

Effect of RT on HbA1c, BMI, and MS in Patients with DM (Primary Outcome)

Effect of RT on HbA1c

RT is widely recognized as an effective nonpharmacological intervention for glycemic control in patients with DM [20]. HbA1c serves as the primary clinical marker of long-term glycemic status, reflecting average blood glucose levels [20]. The present study demonstrated that RT significantly reduced HbA1c in both middle-aged and older patients with DM (Figure 2). Although no statistically significant differences were observed between subgroups, the reduction was more

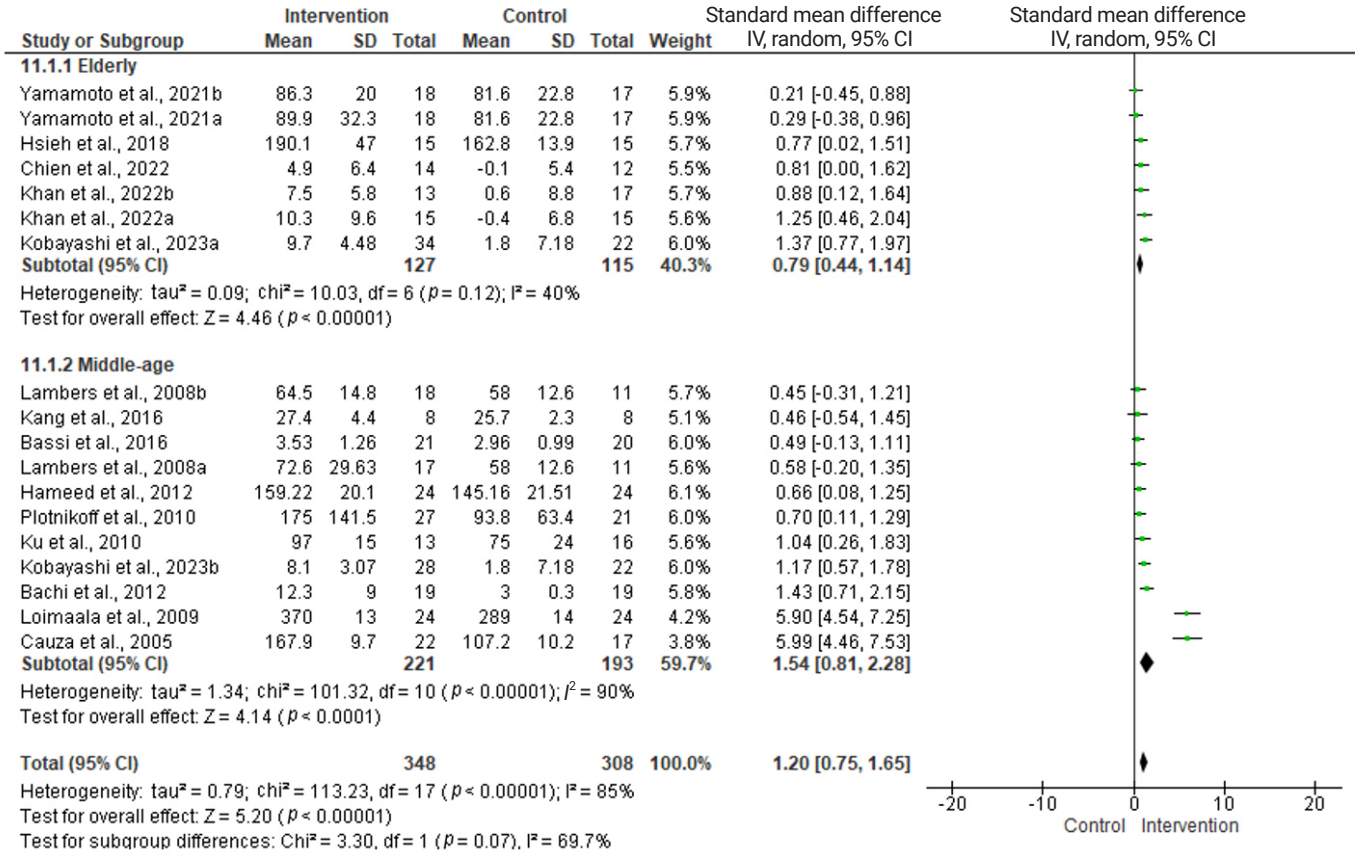


Figure 4. Effect of resistance training on muscle strength (lower limbs).
SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

pronounced in middle-aged participants. This greater reduction may be attributed to higher metabolic flexibility in middle-aged individuals, enabling improved insulin sensitivity, enhanced skeletal muscle glucose uptake through glucose transporter type 4 (GLUT-4) translocation, and greater mitochondrial function following consistent RT compared with older adults [47]. The middle-aged group generally performed higher-intensity exercises—using weight machines, strength training, or endurance training—whereas the older adults more often engaged in progressive RT, elastic bands, isokinetic strength, or sandbag exercises. Training duration also differed slightly: middle-aged participants trained for 8 to 52 weeks, while older participants trained for 12 to 48 weeks. As supported by previous studies, higher-intensity RT produces greater improvements in insulin sensitivity and HbA1c [48]. Middle-aged adults typically tolerate higher-intensity training better than older adults, resulting in more substantial benefits. In addition, muscles in middle-aged individuals retain a stronger adaptive capacity, whereas older adults experience sarcopenia, which diminishes training responsiveness. These adaptations—greater insulin sensitivity and improved glucose metabolism—likely explain the more significant HbA1c reduction observed in middle-aged patients [49].

Effect of RT on BMI

This review also found that routine RT significantly reduced BMI in both middle-aged and older patients with DM (Figure 3). Defined as muscle-strengthening exercise, RT is increasingly recognized as an adjunctive strategy for regulating body composition and glycemic control [7,42,43]. In middle-aged patients, RT was particularly effective in decreasing BMI by reducing fat mass while increasing lean muscle [7]. Gains in muscle mass elevate resting metabolic rate, promoting higher energy expenditure even at rest [50]. RT further increases insulin sensitivity, which improves glucose and lipid metabolism, reduces fat storage, and supports long-term weight management [7,18]. Previous studies also reported that routine RT can lower BMI and waist circumference in overweight individuals with DM [38].

In older patients, RT significantly reduced BMI; however, the degree of reduction was smaller compared to middle-

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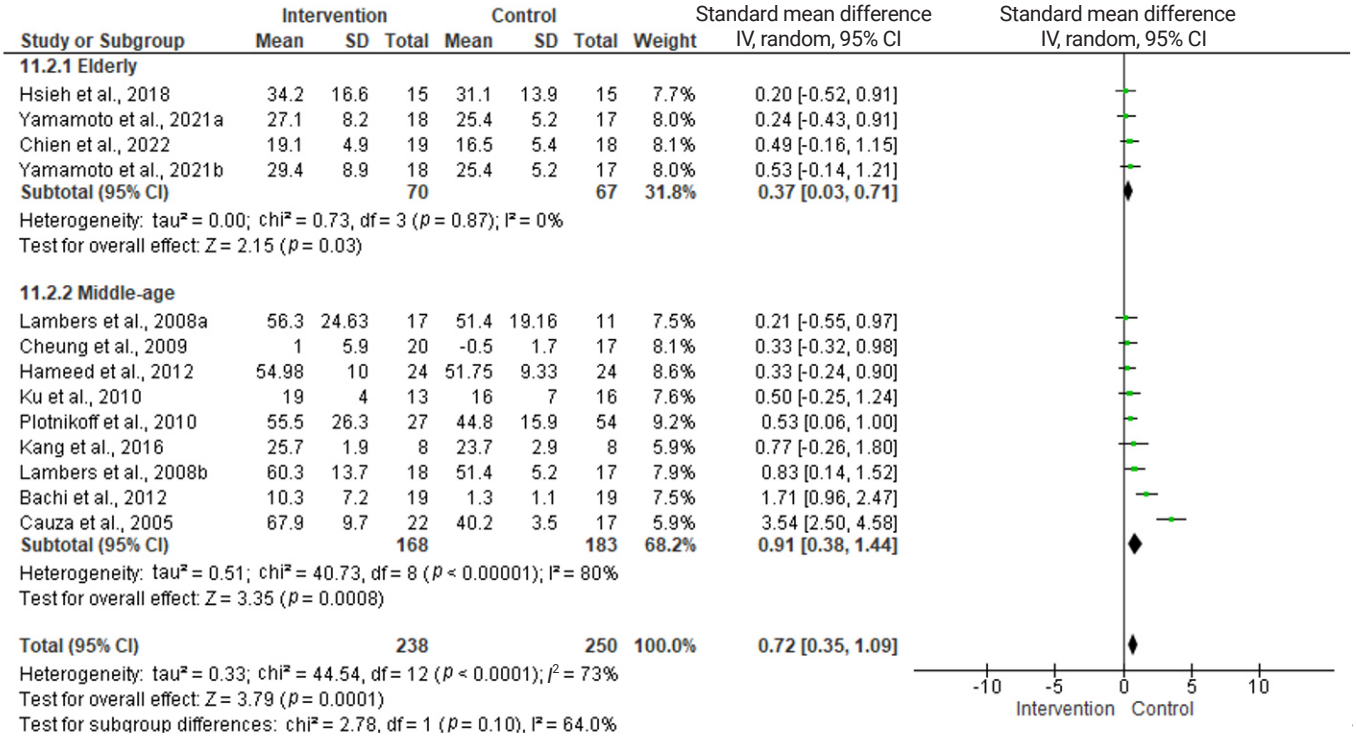


Figure 5. Effect of resistance training on muscle strength (upper limbs).
SD, standard deviation; IV, inverse variance; CI, confidence interval; df, degrees of freedom.

aged patients (Figure 3). This disparity may be explained by age-related anabolic resistance, reduced exercise tolerance, and the tendency toward sarcopenic obesity, characterized by excessive fat relative to muscle mass [44]. Moreover, the higher training intensity and longer exercise durations typically observed in middle-aged groups may account for the greater BMI reduction compared to older groups.

Effect of RT on MS

Patients with DM often experience accelerated muscle mass and strength loss, known as diabetic sarcopenia [4,12,20]. This condition contributes to impaired mobility, increased fall risk, and reduced quality of life [16]. The progression of metabolic syndrome in DM is linked to factors such as insulin resistance, chronic inflammation, oxidative stress, and impaired muscle protein synthesis [7]. Consequently, RT is increasingly recognized as a therapeutic approach for improving glycemic control and enhancing MS in this population [20]. This review found that RT significantly improved both lower- and upper-limb MS in middle-aged and older patients with DM, with greater effects observed in the middle-aged group (Figure 4). RT involves repeated muscle contractions against resistance, producing a mechanical stimulus that promotes protein synthesis and helps counteract sarcopenia. These adaptations are closely correlated with significant gains in MS among DM patients [28]. Furthermore, RT enhances skeletal muscle insulin sensitivity by increasing GLUT-4 expression and improving glucose utilization efficiency [47], leading to greater strength and contractility [51]. However, the magnitude of improvement differs with age: training intensity and duration exert a stronger influence on MS outcomes in middle-aged patients compared to older patients.

Effect of RT on Lipid Profiles, VO_2 Peak, and Serious Events in Patients with DM (Secondary Outcome)

Effect of RT on lipid profiles

Patients with DM commonly exhibit dyslipidemia, typically characterized by elevated triglycerides, reduced HDL, and increased small dense LDL particles [52]. RT has long been recommended as a strategy to improve MS and glycemic control [53], and the present review confirms its benefits for lipid metabolism. Regular RT substantially increased HDL, reduced LDL, and lowered triglycerides, yielding clinically meaningful improvements in lipid profiles. However, total cholesterol was not significantly reduced in middle-aged patients (Figures S3–S6; Table 2). This may be explained

by persistent insulin resistance during middle age, which can drive excessive hepatic very-low-density lipoprotein synthesis [54] and maintain overall cholesterol levels. In older patients, RT significantly reduced total cholesterol and LDL and increased HDL, but had no significant effect on triglycerides (Figures S3–S6; Table 2). The absence of triglyceride reduction may be linked to age-related declines in lipoprotein lipase activity in skeletal muscle [55], which limits the capacity of RT to influence triglyceride metabolism in this subgroup.

Effect of RT on VO_2 peak

Patients with DM often present with reduced VO_2 peak due to mitochondrial dysfunction, insulin resistance, and impaired muscle capillarization [56]. These limitations increase the risk of cardiovascular complications and lower quality of life [40]. RT has been recommended as a rehabilitative intervention to improve muscle efficiency and mitochondrial capacity [56], thereby enhancing VO_2 peak. Consistent with this rationale, the present review showed that RT significantly increased VO_2 peak in both middle-aged and older patients, with greater improvements in the latter (Figure S7).

Effect of RT on serious events

Although RT involves physical exertion, this review found no evidence of serious adverse events among DM patients participating in RT programs (Figure S8). Nevertheless, caution is warranted. International guidelines recommend that exercise-based rehabilitation for DM be conducted either in facilities experienced with this patient population or in supervised home-based settings. In all cases, careful monitoring of blood glucose levels during RT is essential to ensure safety.

Limitations of the Study

This review has several limitations. First, publication bias may exist in some of the included studies, and the scope was restricted to English-language publications; therefore, both publication bias and limited generalizability are unavoidable. These biases were mitigated by involving 3 independent reviewers, conducting an extensive search across 6 databases, and applying strict inclusion criteria. Second, high heterogeneity was observed, particularly regarding the effects of RT on primary outcomes. To address this, a meta-regression stratified analyses by age group (middle-aged and older), and sensitivity analyses were conducted on studies with a high risk of bias, which yielded comparable pooled effect sizes. These findings suggest that the results are robust and reliable. Third, this review did not conduct subgroup analyses based on exercise intensity, which may have obscured variations in the effects of RT. Future research should stratify participants by exercise intensity to better evaluate the differential impact of RT in patients with DM. Additionally, comorbid conditions present in DM patients, which were not the primary focus of this review, may have influenced outcomes. Future studies should incorporate subgroup analyses categorized by DM type, sex, and RT modality to strengthen the evidence base on RT's effectiveness in this population.

Conclusion

This meta-analysis demonstrated that RT provides substantial benefits for patients with DM. The analysis evaluated RT interventions in middle-aged and older adults with DM, including elastic bands, progressive exercises, sandbag exercises, isokinetic strength and endurance exercises, and weight-machine–based training. Interventions were performed either in facilities experienced in managing DM patients or in supervised home-based programs. The results revealed that RT significantly reduced HbA1c and BMI levels and improved MS in both upper and lower limbs. Importantly, RT was well tolerated, and no serious adverse events were reported. However, careful monitoring of blood glucose levels before and during RT remains essential for patient safety. Overall, RT is a recommended rehabilitation strategy for patients with DM, with demonstrated benefits in glycemic control, body composition, and MS.

Supplementary Material

Figure S1. Risk of bias; **Figure S2**. Funnel plots. **Figure S3.** Effect of resistance training on cholesterol; **Figure S4.** Effect of resistance training on triglycerides; **Figure S5.** Effect of resistance training on high-density lipoprotein; **Figure S6.** Effect of resistance training on low-density lipoprotein; **Figure S7.** Effect of resistance training on VO_2 peak; **Figure S8.** Effect of resistance training on serious events. Supplementary data are available at https://doi.org/10.24171/j.phrp.2025.0268.

Notes

Ethics Approval

This study was registered with PROSPERO (CRD420251063715).

Conflicts of Interest

The authors have no conflicts of interest to declare.

Funding

None.

Availability of Data

All data generated or analyzed during this study are included in this

published article. For other data, these may be requested through the corresponding author.

Authors' Contributions

Conceptualization: AQD, PMNB; Data curation: AQD, DMR; Formal analysis: all authors; Investigation: AQD, PMNB; Methodology: all authors; Project administration: AQD, DMR; Supervision: DMR; Writing–original draft: all authors; Writing–review & editing: all authors. All authors read and approved the final manuscript.

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Original Article

Trends and risk factors for physical and psychological sequelae of induced abortion: a cross-sectional study of contemporary women in the Republic of Korea

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ABSTRACT

Objectives: This study aimed to examine trends and factors associated with severe physical and psychological consequences following induced abortion among women in the Republic of Korea.

Methods: An online survey was conducted of adolescent and adult Korean women aged 13 to 64 years, termed the 2022 Sex and Reproductive Health Survey. Respondents who reported a history of induced abortion were analyzed. Logistic regression models that accounted for individual risk factors were fitted to calculate adjusted odds ratios (aOR).

Results: The prevalence of induced abortion was 20.1% (914 of 4,552 respondents). The most frequent indications for abortion were social reasons, and across all periods, approximately half of the women or more reported non-medical challenges at the time of their most recent abortion. Severe physical and psychological sequelae after abortion increased 5-fold from 1980–1992 to 2013–2022. Among those whose most recent abortion occurred in 2003 or later, the risk of severe psychological sequelae was higher in 2013–2022, after the Korean Constitutional Court upheld the existing criminal codes, than in 2003–2012 (aOR, 2.31; 95% confidence interval, 1.09–4.91).

Conclusion: In the absence of institutionalized safe and respectful abortion services, severe physical and psychological sequelae among women who underwent induced abortion were more likely to occur. These findings highlight the importance of safe, affordable, nondiscriminatory, and respectful abortion care.

Keywords: Abortion; Mental health; Psychological health

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Introduction

Background

Reproductive justice, a framework introduced by Black feminists in the 1990s, emphasizes

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the rights to have children, to not have children, and to parent in safe, supportive environments [1,2]. Women have different reasons for choosing abortion, and their social and economic backgrounds may influence the risk of physical and psychological sequelae after the procedure. The legal and social contexts surrounding induced abortion differ across countries. As of April 2023, 88 countries broadly allow abortion for indications other than saving a woman's life or health. Abortion rates are not significantly different between countries where abortion is highly restricted and those where it is broadly legal [3]. The World Health Organization guidelines for abortion care recommend removing regulatory, policy, and programmatic barriers that hinder access to, and the timely provision of, safe abortion care [4].

In settings where socially indicated abortions are illegal, those seeking abortion services face higher risks of using unsafe methods, lacking standard practice guidelines, and receiving care from unskilled providers. Although generally considered safe, therapeutic abortion and spontaneous miscarriage can lead to various complications [5]; most of these are minor, such as pain, bleeding, infection, and uterine perforation [6–8].

Despite persistent beliefs about negative mental health effects of induced abortion, prior research has shown that severe adverse reactions are rare when the procedure is performed in early pregnancy without legal restrictions [9]. Serious mental health problems after abortion are thought to be triggered or aggravated by the circumstances that led the woman to seek an abortion rather than by the procedure itself [9]. Limited evidence is available regarding the prevalence and associated factors of severe physical and psychological sequelae after abortion in settings with legal restrictions on abortions without medical indications. In 2012, the Constitutional Court of the Republic of Korea ruled that the existing anti-abortion laws were constitutional [10]. Numerous civil requests were subsequently filed to change the laws, and the 2012 decision was reversed in 2019 to decriminalize abortion [11]. However, to date, there has been no institutionalization of safe and respectful abortion services in the Republic of Korea [12]. Women have therefore continued to lack legislative protection, facing ongoing legal uncertainty since 2019 [13]. Such restrictions on access to abortion care may contribute to mental health inequities among women, particularly affecting those of lower socioeconomic status [14].

Objectives

This study assessed trends and risk factors for severe physical and psychological sequelae after abortion in contemporary women in the Republic of Korea.

HIGHLIGHTS

- The most common indications for abortion were social reasons.
- Severe physical and psychological sequelae after abortion increased 5-fold from 1980–1992 to 2013–2022.
- The risk of severe psychological sequelae was higher after the Constitutional Court of the Republic of Korea upheld the criminal codes.

Materials and Methods

Study Design and Setting

We conducted a cross-sectional online study of women aged 13 to 64 years in the Republic of Korea, termed the 2022 Sex and Reproductive Health Survey. Our target sample included 1,000 adolescents (13–18 years) and 3,500 adults (19–64 years). Quotas were set by geographic region (17 metropolitan cities and provinces), age group (1-year intervals for adolescents and 10-year intervals for adults), and education level (high school or below vs. university or above), based on resident registration data from May 2022. The sampling frame was a female survey panel of 231,246 individuals provided by a professional survey company. From this panel, 37,896 potential participants were randomly selected via stratified sampling on these characteristics and invited to complete an online questionnaire. In total, 4,651 responded; after excluding unreliable responses (e.g., identical repetitive answers or inconsistencies in age and menstrual status), 4,552 were retained for analysis [15].

Participants

Among the 4,552 participants (1,019 adolescents and 3,533 adults), we excluded those who did not respond affirmatively to the question about abortion history. This yielded 914 women who reported a history of induced abortion and were eligible to complete a questionnaire about their abortion experience.

Variables and Measurement

The survey employed structured questionnaires to capture the total number of abortions, age at the most recent abortion, primary indication, hardships prior to receiving the procedure, subsequent sequelae, and the year of the most recent abortion. Given Korean Constitutional Court decisions regarding the criminalization (2012) and decriminalization (2019) of induced abortion, we grouped respondents by the year of their most recent abortion into 4 periods: 1980–1992,

1993–2002, 2003–2012, and 2013–2022. Because the legal and social circumstances have not changed substantially since 2019, we combined the 2020–2022 and 2013–2019 cohorts [13]. Regarding the indication for the respondent's most recent abortion, the question was, "What was the primary indication of your latest abortion?" with response options: (1) unwanted pregnancy, (2) maternal indication (medically contraindicated pregnancy), (3) fetal indication (fetal malformation), (4) non-supportive environment, (5) forced by partner or parents, (6) pregnancy by rape, and (7) others. For analysis, we grouped indications into 3 categories: "social" (unwanted pregnancy or non-supportive environment), "medical" (maternal or fetal indications), and "forced" (forced by partner/parents or pregnancy by rape). The primary challenge at the time of abortion was assessed with the question, "What was the biggest challenge when you had your latest abortion?" Response options were: (1) limited knowledge of the procedure, (2) limited information about facilities providing the service, (3) fear of breaking the law, (4) expenses associated with the procedure, (5) concerns regarding sequelae, (6) social stigma, (7) rejection by the facility, and (8) others. We coded hardships as "medical" (concerns regarding sequelae) or "non-medical" (all other hardships).

The sequelae of abortion were assessed using the question, "Did you experience any sequelae after the abortion?" Women could choose from the following options: (1) severe physical sequelae, including uterine perforation and pelvic inflammatory disease; (2) mild physical sequelae, including irregular vaginal bleeding, dysmenorrhea, and vaginitis; (3) severe psychological sequelae, including depression and suicidal ideation; (4) mild psychological sequelae, including anxiety, guilt, and depressed mood; and (5) no sequelae. The survey allowed multiple responses, enabling women to report both severe physical and severe psychological sequelae. Demographic and clinical information, including age at the time of abortion, education level, household income, urbanization level of the residential address, and presence of gynecological conditions at the time of the survey, was collected via self-administered questionnaires. Monthly household income was categorized into 10 levels in increments of Korean won (KRW) 1,000,000 (approximately United States dollar [USD] 700), ranging from < KRW 1,000,000 to ≥ KRW 9,000,000.

Statistical Methods

We described the characteristics of the women, stratified by the year of their most recent abortion, using summary statistics. We examined temporal trends, the composition of non-medical hardship, and the prevalence of severe physical and psychological sequelae after the most recent abortion. The abortion-related factors of interest included in the models were age at the time of abortion, primary challenge at the time of abortion, indication for abortion, and total number of induced abortions. We fitted logistic regression models including all covariates to assess associations between abortion-related factors and severe sequelae. Covariates included age at the survey, year of abortion, urbanization level of the residential address, education level, average monthly household income (<1,626, 1,626–3,252, 3,253–4,878, or >4,878 USD converted from KRW; the response options were <2, 2–4, 4–6, or ≥6 million KRW), total number of abortions, presence of gynecological disease, primary indication for the most recent abortion, and access-related barriers. For the adjusted odds ratios (aORs) of physical and psychological sequelae, we restricted the analyses to those whose most recent abortion occurred in 2003 or later, given the potential for recall bias. Statistical analyses were performed using SAS ver. 9.4 (SAS Institute Inc.).

Ethics Statement

This study was approved by the Institutional Review Board (IRB) of the Korea Institute for Health and Social Affairs (IRB No: 2022-052) and the IRB of the Korea Disease Control and Prevention Agency (IRB No: 2021-04-02-1C-A).

Results

Participants

The lifetime prevalence of induced abortion was 20.1% (914/4,552). Among these women, the most recent abortion occurred in 1980–1992 for 22%, 1993–2002 for 38%, 2003–2012 for 25%, and 2013–2022 for 14% (Table 1). About 70% of women whose most recent induced abortion occurred between 1980 and 1992 were aged 60 years or older. Those whose latest abortion took place between 1993 and 2002 were mostly in their 50s, whereas most women whose latest abortion occurred between 2003 and 2012 were in their 40s.

Descriptive Data

The average age at the time of abortion increased over time. Most women lived in urban areas, and more than half did not have a college or university education. The proportion of university graduates was higher in more recent cohorts, reflecting demographic shifts in women's educational attainment and age at childbirth. The median number of abortions was 1 across all 4 time periods. The most frequent indication for abortion was social, and across all periods, approximately half of the women or more reported a

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Table 1. Characteristics of the study population by year of most recent abortion, Sex and Reproductive Health Survey of the Republic of Korea, 2022

Characteristic	Year of most recent induced abortion[a]			
	1980–1992 (*n* = 203)	1993–2002 (*n* = 347)	2003–2012 (*n* = 233)	2013–2022 (*n* = 131)
Age at survey (y)				
< 20	0 (0)	0 (0)	0 (0)	2 (1.5)
20–29	0 (0)	0 (0)	3 (1.3)	22 (16.8)
30–39	0 (0)	0 (0)	35 (15.0)	43 (32.8)
40–49	1 (0)	68 (19.6)	106 (45.5)	56 (42.7)
50–59	60 (29.6)	197 (56.8)	84 (36.1)	8 (6.1)
60–64	142 (70.0)	82 (23.6)	5 (2.1)	0 (0)
Urbanization level				
Metropolitan city	90 (44.3)	127 (36.6)	102 (43.8)	59 (45.0)
City or town	75 (36.9)	160 (46.1)	97 (41.6)	56 (42.7)
Rural area	38 (18.7)	60 (17.3)	34 (14.6)	16 (12.2)
Education level				
High school or lower	133 (65.5)	222 (64.0)	123 (52.8)	74 (56.5)
College or university	70 (34.5)	125 (36.0)	110 (47.2)	55 (42.0)
Average monthly household income[b]				
< USD 1,626	24 (11.8)	35 (10.1)	10 (4.3)	16 (12.2)
USD 1,626–3,252	82 (40.4)	102 (29.4)	71 (30.5)	42 (32.1)
USD 3,253–4,878	47 (23.2)	112 (32.3)	84 (36.1)	42 (32.1)
> USD 4,878	50 (24.6)	98 (28.2)	68 (29.2)	29 (22.1)
Age at abortion (y)	26.6 ± 3.6	29.8 ± 5.4	31.4 ± 6.7	33.5 ± 7.5
< 30	145 (71.4)	159 (45.8)	85 (36.5)	43 (32.8)
30–39	58 (28.6)	173 (49.9)	114 (48.9)	56 (42.7)
40–49	0 (0)	15 (4.3)	34 (14.6)	32 (24.4)
Total no. of abortions	1.5 ± 1.1	1.5 ± 0.9	1.5 ± 1.1	1.5 ± 0.9
Presence of any gynecological conditions	42 (20.7)	93 (26.8)	94 (40.3)	57 (43.5)
Experience of most recent abortion				
Primary indication				
Social	152 (79.6)	260 (78.5)	178 (78.8)	109 (85.2)
Medical	29 (15.2)	56 (16.9)	35 (15.5)	15 (11.7)
Forced	10 (5.2)	15 (4.5)	13 (5.8)	4 (3.1)
Primary challenge				
Non-medical challenge	84 (44.0)	147 (44.4)	122 (54.0)	96 (75.0)
Severe sequelae after the procedure				
Physical	2 (1.0)	2 (0.6)	10 (4.3)	6 (4.6)
Psychological	7 (3.4)	10 (2.9)	23 (9.9)	19 (14.5)

Data are presented as *n* (%) or mean ± standard deviation. The discrepancy between the column sum and the total number is attributable to missing responses.

USD, US dollar.

[a]These periods were defined based on the years of the Korean Constitutional Court decisions regarding the criminalization and decriminalization of induced abortion (2012 and 2019). [b]Converted from Korean won (KRW). The response options for household income were < 2, 2–4, 4–6, and ≥ 6 million KRW.

primary challenge in the non-medical category at the time of their most recent abortion.

Outcome Data and Main Results

Over the study period, the overall prevalence was 23.7 per 1,000 women for severe physical sequelae and 73.6 per 1,000 women for severe psychological sequelae. Among women whose most recent abortion occurred in 1980–1992, 1% and 3% reported severe physical and severe psychological sequelae, respectively (Figure 1). Among those whose most recent abortion occurred in 2013–2022, severe physical sequelae were reported in 5% and severe psychological sequelae in 15%.

After adjustment for individual risk factors, the risk of severe psychological sequelae was higher in 2013–2022, after

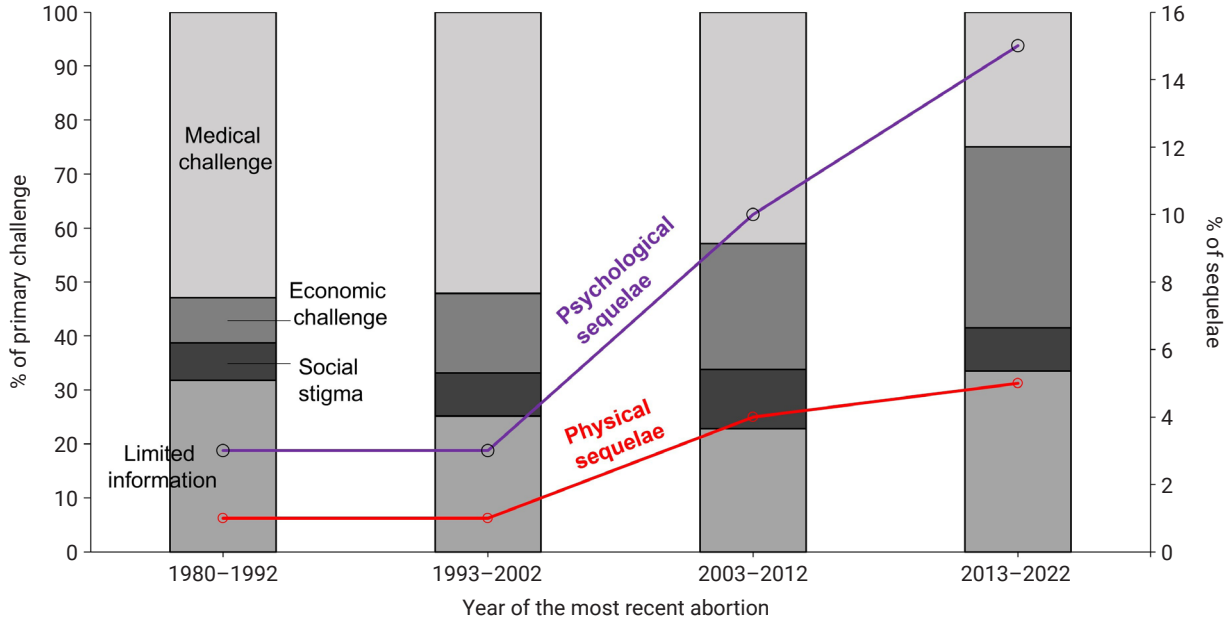


Figure 1. Distribution of primary challenges (including non-medical challenges) and prevalence of severe psychological or physical sequelae after the most recent abortion. Severe physical sequelae included uterine perforation and pelvic inflammatory disease. Severe psychological sequelae included depression and suicidal ideation.

the Constitutional Court decided that the existing criminal codes were constitutional, than in the prior period (aOR, 2.31; 95% confidence interval [CI], 1.09–4.91) (Table 2). An age younger than 30 years was associated with a higher risk of psychological sequelae (aOR, 6.75; 95% CI, 1.73–26.4), though estimates for severe physical sequelae were imprecise due to low prevalence (aOR, 4.20; 95% CI, 0.64–27.37). Non-medical hardship barriers at the time of abortion were associated with a lower risk of severe physical (aOR, 0.21; 95% CI, 0.06–0.72) and severe psychological (aOR, 0.45; 95% CI, 0.21–0.95) sequelae. Compared with abortions performed for medical indications, abortions for social indications were associated with a lower risk of severe physical (aOR, 0.36; 95% CI, 0.06–2.11) and severe psychological (aOR, 0.19; 95% CI, 0.07–0.48) sequelae. A higher total number of abortions was associated with an increased risk of severe physical sequelae (aOR, 1.66; 95% CI, 1.13–2.44), whereas the association between total number of abortions and severe psychological sequelae was close to null.

Discussion

Key Results

The lifetime prevalence of induced abortion in this study is comparable to figures reported in the United States (24.7%), Lesotho (35.25%), South Africa (32.13%), Namibia (26.95%), and Zimbabwe (23.06%) [16,17]. An increased risk of severe physical and psychological sequelae was observed in a sample of contemporary women in the Republic of Korea. Young age at the time of abortion was a risk factor for severe psychological sequelae, whereas social indications for abortion were associated with lower risk of both severe physical and psychological sequelae. The total number of abortions was a risk factor for severe physical sequelae but not for severe psychological sequelae. Our findings imply that eliminating social hardships and protecting against the negative social implications of abortion are important for preventing severe sequelae following induced abortion.

The frequency and severity of sequelae after induced abortion differ according to the operational definition used for measurement and gestational age [18–20]. The estimated complication rates across all health care sources were approximately 2% for medication abortions, 1.3% for first-trimester aspiration abortions, and 1.5% for second-trimester or later abortions. After surgical abortion, the reported prevalence of physical complications ranges from 0.4% to 19.7% [21–23]. The prevalence of depression was 22.5% in a sample of Chinese women seeking an abortion in the first trimester [24]. A longitudinal study in New Zealand showed that 1.5% to 5.5% of overall mental disorders could be attributed to abortions [25]. A recent review observed that women who were denied abortion access demonstrated greater baseline anxiety, and perceived abortion-related stigma was associated with increased psychological distress

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Table 2. Adjusted odds ratios of severe physical and psychological sequelae by year, non-medical hardship, primary indication for the most recent abortion, and total lifetime number of abortions, restricted to 2003 and later; Sex and Reproductive Health Survey of the Republic of Korea, 2022

Risk factor	Severe physical sequelae	Severe psychological sequelae
No. of events/observations	16/364	42/364
Year of abortion		
2003–2012	1.00 (reference)	1.00 (reference)
2013–2022	1.85 (0.52–6.57)	2.31 (1.09–4.91)
Age at the time of abortion (y)		
<30	4.20 (0.64–27.37)	6.75 (1.73–26.4)
30–39	0.48 (0.07–3.47)	2.53 (0.67–9.60)
40–49	1.00 (reference)	1.00 (reference)
Hardship at the time of abortion		
Medical	1.00 (reference)	1.00 (reference)
Non-medical	0.21 (0.06–0.72)	0.45 (0.21–0.95)
Primary cause of abortion		
Medical	1.00 (reference)	1.00 (reference)
Social	0.36 (0.06–2.11)	0.19 (0.07–0.48)
Forced	0.42 (0.03–5.31)	0.87 (0.20–3.86)
Total no. of abortions		
Per 1 additional abortion	1.66 (1.13–2.44)	0.93 (0.62–1.41)

Data are presented as adjusted odds ratio (95% confidence interval). Adjusted odds ratios were adjusted for all risk factors, age at survey, urbanization level of residence, education level, average household income, and presence of any gynecological disease.

[26]. Although our measurement of severe sequelae was based on self-reported data, the prevalence of physical and psychological sequelae in our study population largely aligns with previous studies. The prevalence of severe sequelae was generally lower than that reported in prior research [27]. Unlike the Republic of Korea, other countries have legal systems that broadly allow induced abortion on social and economic grounds; thus, the prevalence of severe sequelae reported before 2021 may have been underestimated in our study. Because of the national family planning campaign in the Republic of Korea from the 1960s to the 1980s, abortion was widely accessible despite being generally illegal [28–30]. When the national policy shifted to childbirth promotion as fertility declined, the government of the Republic of Korea revived enforcement of the criminal code on abortion in 2012 [28]. Given this strong national stance on banning abortion, many women seeking abortion may have been forced to undergo the procedure in less safe environments [31], leading to a higher risk of severe physical and psychological sequelae during this period than in the past.

The inverse association between social indications for abortion and severe psychological sequelae underscores the importance of supporting women's decisions to minimize the psychological impact of induced abortion. Evidence indicates that induced abortion itself does not cause deleterious psychological effects, particularly when the reason for termination is insufficient support for the pregnancy [32]. In contrast, women who undergo the procedure against their will, for a medical indication, or under pressure from others are more likely to experience subsequent mental health problems [33]. A woman whose pregnancy is terminated for social reasons may feel that she has fully exercised her reproductive rights even without legal protections for induced abortion [34].

Limitations

Given the cross-sectional design, our findings should be interpreted with caution due to several limitations. First, differential recall bias is possible: women who underwent induced abortion several decades ago may not accurately recall their experiences of severe sequelae. However, our subgroup analysis restricted to more recent abortions showed similar results, suggesting that recall bias may have been minimal. Second, because some women may feel guilt or discomfort discussing their experiences of induced abortion, they may have responded inaccurately and therefore been excluded from the analysis. Third, the demographic variables used in our explanatory models may not reflect women's circumstances at the time of abortion, introducing potential bias in the risk estimates. Prospective studies that collect contemporaneous demographic data, preexisting health conditions, and the quality of medical

services provided are needed to confirm our findings. Fourth, outcomes were based on self-reported responses, which limits interpretability. Fifth, combining the years 2013–2022 into a single analytic category without distinguishing the impact of the 2019 Constitutional Court ruling might have underestimated the risk of sequelae. Because the number of events during 2013–2022 was relatively small, model fitting was challenging, especially with multiple covariates.

Interpretation and Generalizability

The findings of this study may have limited the generalizability due to the specific characteristics of our study population. Nevertheless, leveraging a large sample of women in the Republic of Korea, our study provides valuable insights that meaningfully contribute to a field where current knowledge remains limited.

Conclusion

In the absence of institutionalized safe and respectful abortion services, the risk of severe physical and psychological sequelae was higher for recent induced abortions, whereas non-medical or socially motivated abortions were associated with a lower risk of severe psychological complications. These findings highlight the importance of safe, affordable, nondiscriminatory, and respectful abortion care for women's health.

Notes

Ethics Approval

This study was approved by the IRB of the Korea Institute for Health and Social Affairs (IRB No: 2022-052) and the IRB of the Korea Disease Control and Prevention Agency (IRB No: 2021-04-02-1C-A), and was performed in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained for publication of this study and accompanying images.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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Availability of Data

The datasets are not publicly available.

Authors' Contributions

Conceptualization: EP; Data curation: ES, JP; Formal analysis: SAC; Funding acquisition: EP; Methodology: SAC; Supervision: EP; Writing–original draft: SAC; Writing–review & editing: all authors. All authors read and approved the final manuscript.

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Original Article

A machine learning approach for predicting suicidal ideation among family members of persons with disabilities: a cross-sectional study in the Republic of Korea

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ABSTRACT

Objectives: Although family members of persons with disabilities face elevated suicide risk, predictive models remain underdeveloped in Korean contexts. This study aimed to develop machine learning–based predictive models for suicidal ideation among family members of persons with disabilities and examine differential risk patterns by disability onset type.

Methods: This cross-sectional study analyzed 124,783 adult family members (59.9% spouses, 20.3% parents/ascendants, 14.6% adult children, 5.2% extended family) from the 2018 Korean Disability and Life Dynamics Panel using survey weights. Four predictive models, including machine learning approaches, were compared using 31 variables. The dataset was divided into training (70%) and test (30%) sets, with stratified analyses comparing congenital and acquired disability groups.

Results: Among the 124,783 family members analyzed, least absolute shrinkage and selection operator (LASSO) with cross-validation achieved optimal performance (area under the receiver operating characteristic curve, 0.875 training; 0.853 test). LASSO selected 16 of 31 variables for the total sample, with family members' depression as the strongest predictor (β = 0.554), followed by disabled persons' suicidal ideation (β = 0.425). Stratified LASSO analyses revealed that national basic livelihood beneficiary status was the strongest predictor for families with congenital disability (β = 0.541), while family members' depression was the strongest predictor for families with acquired disability (β = 0.562), demonstrating distinct predictive patterns by disability onset.

Conclusion: These findings show that predictive factors differ substantially by disability onset type, indicating the need for tailored intervention approaches and offering an evidence-based foundation for targeted suicide prevention strategies.

Keywords: Age of onset; Family; Machine learning; Persons with disabilities; Suicidal ideation

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Introduction

Suicide is a major global public health concern and one of the leading causes of death worldwide. Each year, approximately 703,000 individuals die by suicide [1]. In the Republic of Korea, the suicide rate is 24.6 per 100,000, which is more than twice the average rate reported by the Organisation for Economic Co-operation and Development (OECD) [2]. Although suicide rates in many OECD countries have declined [3], the Republic of Korea's rate has remained persistently high [4], underscoring the urgent need for accurate prediction tools that can identify high-risk groups and facilitate early intervention.

In the Republic of Korea, families of persons with disabilities face intensified challenges due to unique sociocultural dynamics. Confucian cultural norms emphasizing familial responsibility position caregiving as a moral obligation rather than a discretionary role [5]. Despite government programs such as disability pensions and personal assistance services, these supports often prove inadequate, leaving families with primary caregiving responsibilities while facing limited institutional support [6,7]. Persistent social stigma—particularly surrounding mental or developmental disabilities—contributes to family isolation and psychological strain, as families may withdraw from social activities to avoid discrimination [8,9]. These culturally specific pressures, combined with universal caregiving challenges, create a uniquely vulnerable population requiring targeted intervention strategies [10–12].

Family members of persons with disabilities represent one of the most vulnerable groups for suicide risk. Research indicates that suicide ideation rates among family caregivers reach 24.9%, roughly 5 times higher than the general population rate of 4.7% [6]. Depression scores in this population average 20 points, which is substantially higher than scores seen in other high-risk groups such as older adults [9]. Multiple stressors contribute to this elevated risk, including caregiving burden, economic hardship, social isolation, and family conflict, which together create complex vulnerability patterns requiring comprehensive prediction strategies [10–12]. Despite this pronounced risk, existing suicide prediction research has focused primarily on the general population or other vulnerable groups such as older adults and individuals with mental illness, leaving a critical gap in evidence-based prediction tools for family members of persons with disabilities [13,14].

Furthermore, families of persons with disabilities do not represent a uniform population, and the timing of disability onset may create distinct vulnerability profiles that require different predictive approaches. Prior studies have shown that persons with congenital versus acquired disabilities exhibit different suicide risks and contributing factors [15–17]. Likewise, families of persons with congenital disabilities face challenges that differ fundamentally from those confronting acquired disabilities. Families dealing with congenital disabilities often experience chronic strains and long-term adaptation processes due to lifelong caregiving responsibilities [5]. In contrast, families facing acquired disabilities may undergo acute adjustment crises following sudden onset, sharing experiences of grief, trauma, and disruption of anticipated life trajectories with the disabled individual [18]. These differing contexts suggest that effective predictive models should consider disability onset type. However, no studies to date have developed separate predictive algorithms for families of persons with congenital versus acquired disabilities.

Moreover, existing approaches to suicide prediction among families of persons with disabilities face methodological limitations that hinder comprehensive risk assessment. Most studies have relied on traditional statistical methods that examine limited numbers of variables because of sample size constraints and multicollinearity issues [14,15]. Additionally, the small body of prior research on this population makes it difficult to identify optimal predictors for different subgroups. Machine learning approaches can address these challenges by analyzing multiple risk factors simultaneously while identifying new patterns without prior assumptions [19]. These methods are particularly valuable for comparing predictive factors across distinct groups and

HIGHLIGHTS

- This study developed, to our knowledge, the first machine learning model designed to predict suicide risk among family members caring for persons with disabilities in the Republic of Korea.
- Family members' depression was the strongest overall predictor, and suicide risk was closely linked between disabled persons and their families.
- Predictive factors differed by disability onset. Economic hardship showed the strongest predictive association for families with congenital disabilities, whereas depression was the strongest predictor for families dealing with acquired disabilities.
- These findings offer guidance for developing tailored suicide prevention strategies for families of persons with congenital versus acquired disabilities.

generally demonstrate superior predictive performance [20,21], making them well suited for developing evidence-based prediction models.

This study is guided by 2 complementary theoretical frameworks. First, the stress process model posits that disability-related primary stressors (e.g., functional limitations) give rise to secondary stressors (e.g., economic strain, family conflict) that accumulate over time, with differential impacts depending on disability onset timing [22]. This model helps explain why families dealing with congenital disabilities may experience chronic strain due to lifelong caregiving, whereas families confronting acquired disabilities often face acute adaptation crises. Second, ecological systems theory emphasizes that suicidal ideation arises from complex interactions across multiple system levels—individual factors (depression, self-esteem), microsystem factors (family relationships, caregiving burden), and exosystem factors (social support, economic resources) [23]. This multi-level perspective informed our comprehensive variable selection across individual, family, and social domains, allowing us to account for the interconnected nature of risk factors rather than examining isolated predictors. These frameworks suggest that effective prediction models must consider both the temporal dynamics of stress accumulation and the multi-systemic nature of suicide risk.

Based on these theoretical foundations, we developed machine learning predictive models for suicidal ideation among family members of persons with disabilities using nationally representative Korean data. We incorporated a comprehensive assessment of risk factors across individual, family, and social dimensions and conducted stratified analyses to investigate differential predictive patterns between families of persons with congenital versus acquired disabilities. The study aimed to (1) develop machine learning models for predicting suicidal ideation among family members of persons with disabilities and compare their performance with traditional statistical approaches, (2) examine differences in risk factors and predictive patterns between congenital and acquired disability groups through stratified analysis, and (3) identify the strongest predictor variables within each disability onset group to guide evidence-based suicide prevention interventions and inform resource allocation strategies.

Materials and Methods

Study Population and Datasets

This research drew upon data from the 2018 Disability and Life Dynamics Panel (DLDP), a comprehensive nationwide assessment of living conditions among people with disabilities in the Republic of Korea. The DLDP was established to generate data on the life circumstances of disabled individuals and their families and to provide essential information for policy development.

The DLDP employed stratified sampling based on disability type, severity, sex, and other relevant characteristics to ensure adequate representation of registered disabled persons, excluding those residing in institutional facilities. Potential participants were initially contacted by telephone to explain the purpose of the research, and data collection proceeded only after informed consent was obtained. Face-to-face structured interviews were conducted using Tablet Assisted Personal Interviewing, with interviewers trained to approach individuals with disabilities ethically and respectfully. Detailed methodological information is available through the Korea Disabled People's Development Institute website (https://www.koddi.or.kr/data/research01_view.jsp?brdNum=7422083).

From an initial pool of 6,121 disabled individuals, 284 declined participation, resulting in 5,837 respondents who consented to the survey. During data processing, 236 cases were identified as having missing values on key variables, yielding 5,601 respondents with complete data. Complete case analysis was applied, given the low proportion of missing data (4.0%), which provides unbiased estimates when missingness is below 20% and is unrelated to the outcome [24]. For this study, we identified 3,214 disabled individuals living with family members after excluding those who lived alone. Our primary research subjects were the 2,839 adult family caregivers who had lived with these disabled individuals (aged 14 or older) for at least 6 months. Using household identifiers, we linked data from family caregivers with information about the disabled individuals they lived with, enabling us to analyze how the characteristics of disabled persons were associated with the experiences of their family members.

Adjusted sample weights provided by the DLDP were used to account for non-responses and stratified sampling of specific subpopulations, allowing the estimates to be representative of the disabled population in Korea. Weighting procedures began with a base sampling weight, followed by non-response adjustments and post-stratification to match demographic distributions for region, disability type, severity, sex, and age. Descriptive statistics incorporated survey weights to reflect the complex sampling design, whereas penalized regression analyses were performed on unweighted data using STATA ver. 16.0 (StataCorp LLC).

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Variables

The dependent variable was suicidal ideation among family members of persons with disabilities, assessed with a single dichotomous item: "Have you seriously thought about suicide during the past year from the date of the survey?" (0 = no, 1 = yes).

Based on previous research, factors associated with suicidal ideation were categorized into 4 domains [7–9,11,17,18,24–27]. Individual characteristics of family members included sex (female = 0, male = 1), age (≤ 20 to 71–80 years), educational level (none to college or higher), depression (Center for Epidemiologic Studies Depression Scale [CESD]-11), self-esteem, employment status (unemployed = 0, employed = 1), marital status (single/divorced/widowed = 0, married = 1), and chronic illness (no = 0, yes = 1).

Individual characteristics of persons with disabilities included suicidal ideation (0 = no, 1 = yes), sex (female = 0, male = 1), age (21–30 to ≥ 81 years), depression (CESD-11), disability grade (mild = 0, severe = 1), disability type (external physical = 0, internal physical = 1, mental = 2), disability acceptance, activities of daily living (ADL), and meal companionship (eating with others = 0, eating alone = 1).

Family characteristics included the number of family members (2, 3, ≥ 4), family type (ascendant relatives = 0, spouse = 1, descendants = 2, extended family = 3), national basic livelihood recipient status (no = 0, yes = 1), log of family income, financial crisis level, family strengths, interfamilial conflict (no = 0, yes = 1), and caregiving burden.

Social characteristics included social relationship satisfaction, frequency of contact with friends, frequency of professional contact, and leisure activity companion patterns (non-participant = 0, participates alone = 1, participates with family = 2, participates with acquaintances = 3).

Data Analysis

To identify factors associated with suicidal ideation among family members of persons with disabilities, we applied machine learning approaches for predictive modeling. The dataset was randomly divided into a training set (70%) and a test set (30%) to evaluate model performance.

We compared 4 predictive techniques: multivariate logistic regression as the baseline model; least absolute shrinkage and selection operator (LASSO) with cross-validation (CV) selection (α = 1, 10-fold CV for optimal λ); LASSO with adaptive selection (α = 1, varying penalty weights); and ridge regression (α = 0). These penalized regression methods were selected for their ability to perform simultaneous variable selection and regularization, yielding predictive performance comparable to more computationally intensive algorithms such as random forest or support vector machines in datasets of this dimensionality (31 variables), while maintaining superior interpretability and efficiency [19–21]. Because our primary aim was to identify actionable predictors for policy and clinical interventions, interpretable models with clear coefficient estimates were prioritized over black-box approaches such as neural networks or tree-based ensembles. Although further hyperparameter tuning beyond cross-validated λ could be performed, penalized linear models typically show limited additional gains relative to non-linear algorithms, and our CV approach sufficiently optimized the main regularization parameter.

Model performance was evaluated using established metrics: area under the receiver operating characteristic curve (AUC), sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), accuracy, and F1-score. AUC values between 0.7–0.8 indicate acceptable discrimination, 0.8–0.9 excellent discrimination, and values above 0.9 outstanding discrimination [25]. Sensitivity and specificity assessed the accuracy of identifying true positive and true negative cases, respectively. PPV and NPV measured the proportion of correct positive and negative predictions, while the F1-score represented the harmonic mean of precision and recall. The optimal model was selected based on having the highest AUC, PPV, NPV, and F1-score in both the training and test datasets [28,29]. To support clinical interpretability, we presented standardized coefficients as indicators of relative importance and conducted stratified analyses to identify group-specific risk patterns that would provide practical screening insights without requiring advanced computational tools.

After determining the best-performing model, we calculated penalized coefficients from the LASSO models and compared them with coefficients from the multivariate logistic regression to assess the effects of regularization. Standardized coefficients were calculated to compare relative variable importance across groups, rather than to estimate effect sizes. We also performed stratified analyses comparing risk factors between family members of persons with congenital disabilities and those with acquired disabilities to identify potential differences in predictive patterns. Standardized coefficients were compared across 3 groups (total sample, congenital disability, and acquired disability) to determine the most influential predictors for each group.

Ethics Statement

The survey conducted by the Korea Disabled Persons Development Institute received approval from Korean Public Institutional Review Board (No: P01-2018-09-22-004).

Informed consent was waived because of the retrospective nature of this study.

Results

Characteristics of the Study Participants

Based on the complex sample analysis, Table 1 presents the characteristics of the study participants in the weighted sample, which included 124,783 family members of persons with disabilities. Among them, 113,403 (90.9%) were family members of persons with acquired disabilities, and 11,380 (9.1%) were family members of persons with congenital disabilities.

Development of a Predictive Model for Suicidal Ideation among Family Members of Persons with Disabilities

To develop predictive models for suicidal ideation among

Table 1. Characteristics of the study participants

Variable	Total (*n* = 124,783)	Acquired (*n* = 113,403)	Congenital (*n* = 11,380)
Individual characteristics of family members			
Sex of family members			
Female	76,517 (61.320)	77,216 (61.880)	70,303 (56.340)
Male	48,266 (38.680)	47,567 (38.120)	54,480 (43.660)
Age of family members (y)			
≤20	661 (0.530)	686 (0.550)	437 (0.350)
21–30	8,311 (6.660)	8,298 (6.650)	8,348 (6.690)
31–40	9,933 (7.960)	9,920 (7.950)	10,107 (8.100)
41–50	15,598 (12.500)	14,849 (11.900)	22,411 (17.960)
51–60	37,447 (30.010)	37,360 (29.940)	38,221 (30.630)
61–70	34,590 (27.720)	34,914 (27.980)	31,632 (25.350)
71–80	18,243 (14.620)	18,755 (15.030)	13,626 (10.920)
Education level of family members			
None	4,617 (3.700)	4,829 (3.870)	2,633 (2.110)
Elementary	19,516 (15.640)	19,628 (15.730)	18,455 (14.790)
Middle school	18,817 (15.080)	18,455 (14.790)	21,974 (17.610)
High school	54,068 (43.330)	53,919 (43.210)	55,366 (44.370)
≤College	27,777 (22.260)	27,939 (22.390)	26,367 (21.130)
Depression of family members	20.660±6.490	20.800±6.530	19.410±6.000
Self-esteem of family members	28.410±3.620	28.400±3.620	28.520±3.660
Employment status of family members			
Unemployed	68,830 (55.160)	69,741 (55.890)	60,632 (48.590)
Employed	55,953 (44.840)	55,042 (44.110)	64,151 (51.410)
Marital status of family members			
Single/divorced/widowed	29,586 (23.710)	28,862 (23.130)	36,025 (28.870)
Married	95,197 (76.290)	95,921 (76.870)	88,758 (71.130)
Chronic illness of family members			
No	72,561 (58.150)	72,574 (58.160)	72,499 (58.100)
Yes	52,222 (41.850)	52,209 (41.840)	52,284 (41.900)
Suicidal ideation of family members			
No	116,959 (93.730)	116,722 (93.540)	119,068 (95.420)
Yes	7,824 (6.270)	8,061 (6.460)	5,715 (4.580)
Individual characteristics of persons with disabilities			
Suicidal ideation of persons with disabilities			
No	104,606 (83.830)	103,932 (83.290)	110,720 (88.730)
Yes	20,177 (16.170)	20,851 (16.710)	14,063 (11.270)
Sex of persons with disabilities			
Female	56,527 (45.300)	55,479 (44.460)	65,910 (52.820)
Male	68,256 (54.700)	69,304 (55.540)	58,873 (47.180)

(Continued on the next page)

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Table 1. Continued

Variable	Total (*n* = 124,783)	Acquired (*n* = 113,403)	Congenital (*n* = 11,380)
Age of persons with disabilities (y)			
21–30	1,622 (1.300)	1,123 (0.900)	6,152 (4.930)
31–40	9,496 (7.610)	6,738 (5.400)	34,265 (27.460)
41–50	9,234 (7.400)	8,011 (6.420)	20,215 (16.200)
51–60	15,298 (12.260)	15,236 (12.210)	15,822 (12.680)
61–70	37,672 (30.190)	38,733 (31.040)	28,126 (22.540)
71–80	40,168 (32.190)	42,788 (34.290)	16,696 (13.380)
≥81	11,293 (9.050)	12,166 (9.750)	3,519 (2.820)
Depression of persons with disabilities	22.810 ± 7.210	23.060 ± 7.260	20.560 ± 6.360
Grade of disability of persons with disabilities			
Mild	56,352 (45.160)	57,824 (46.340)	43,063 (34.510)
Severe	68,431 (54.840)	66,959 (53.660)	81,720 (65.490)
Type of disability of persons with disabilities			
External physical disabilities	79,025 (63.330)	81,658 (65.440)	55,366 (44.370)
Internal physical disabilities	36,299 (29.090)	34,141 (27.360)	55,803 (44.720)
Mental disabilities	9,446 (7.570)	8,984 (7.200)	13,626 (10.920)
Disability acceptance of persons with disabilities	27.450 ± 5.430	27.340 ± 5.430	28.470 ± 5.290
ADL of persons with disabilities	23.730 ± 10.650	24.020 ± 10.800	21.100 ± 8.850
Eating alone			
No	86,362 (69.210)	86,687 (69.470)	83,480 (66.900)
Yes	38,421 (30.790)	38,096 (30.530)	41,303 (33.100)
Family characteristics of households with disability			
No. of family members			
2	60,133 (48.190)	62,030 (49.710)	43,063 (34.510)
3	34,365 (27.540)	33,205 (26.610)	44,822 (35.920)
≤4	30,285 (24.270)	29,549 (23.680)	36,911 (29.580)
Family type			
Ascendant relatives	25,269 (20.250)	21,338 (17.100)	60,632 (48.590)
Spouse	74,770 (59.920)	78,389 (62.820)	42,177 (33.800)
Descendants	18,243 (14.620)	19,042 (15.260)	10,981 (8.800)
Extended family members	6,501 (5.210)	6,002 (4.810)	10,981 (8.800)
Beneficiary of national basic livelihood			
No	106,976 (85.730)	107,837 (86.420)	99,302 (79.580)
Yes	17,807 (14.270)	16,946 (13.580)	25,481 (20.420)
Log of family income	4.900 ± 3.850	4.890 ± 3.900	5.050 ± 3.430
Financial crisis	16.910 ± 5.470	16.940 ± 5.470	16.630 ± 5.490
Family strengths	64.400 ± 10.500	64.440 ± 10.500	64.020 ± 10.440
Interfamilial conflict			
No	87,373 (70.020)	87,860 (70.410)	83,043 (66.550)
Yes	37,410 (29.980)	36,923 (29.590)	41,740 (33.450)
Caregiving burden	1.790 ± 1.400	1.830 ± 1.420	1.520 ± 1.260
Social characteristics of households with disability			
Social relationship satisfaction	5.430 ± 1.730	5.420 ± 1.710	5.490 ± 1.880
Fre-quency of contact with friends	3.290 ± 2.010	3.300 ± 2.010	3.170 ± 2.030
Frequency of professional contact	2.030 ± 1.080	2.030 ± 1.080	2.050 ± 1.070
Leisure activity companion			
Non-participant	16,609 (13.310)	16,946 (13.580)	13,626 (10.920)
Participates alone	59,422 (47.620)	58,798 (47.120)	65,024 (52.110)
Participates with family	37,135 (29.760)	37,897 (30.370)	30,322 (24.300)
Participates with acquaintances	11,605 (9.300)	11,131 (8.920)	15,822 (12.680)

Data are presented as *n* (%) or mean ± standard deviation.
ADL, activities of daily living.

family members of persons with disabilities, we randomly divided the dataset into a training set (70%) and a test set (30%). Four different machine learning approaches were evaluated: multivariate logistic regression, LASSO with CV selection, LASSO with adaptive selection, and ridge regression.

Table 2 presents the performance metrics of the 4 predictive models in both the training and test sets. In the training set, all models demonstrated good discriminative ability, with AUC values ranging from 0.869 to 0.875. The LASSO with CV selection model showed the highest AUC (0.875), followed closely by multivariate logistic regression (0.872), ridge regression (0.870), and LASSO with adaptive selection (0.869). ROC curves for all four models in the training set are shown in Figure S1. When applied to the test set, all models showed the expected slight decreases in performance, with AUC values ranging from 0.848 to 0.853, indicating good generalizability. ROC curves for the test set are presented in Figure S2. For sensitivity, which reflects the ability to correctly identify individuals with suicidal ideation, the training set values ranged from 0.415 to 0.487, with LASSO with CV selection performing best (0.487). In the test set, both multivariate logistic regression and LASSO with CV selection achieved the highest sensitivity (0.461), followed by LASSO with adaptive selection (0.438) and ridge regression (0.388). All models exhibited high specificity in both the training (0.955–0.965) and test sets (0.948–0.957), with ridge regression yielding the highest specificity in both datasets (0.965 and 0.957, respectively). PPV values ranged from 0.393 to 0.421 in the training set and from 0.371 to 0.396 in the test set, with LASSO with CV selection consistently showing the highest PPV. NPV was consistently high across all models in both the training (0.964–0.968) and test sets (0.959–0.964). In terms of overall accuracy, values ranged from 0.925 to 0.930 in the training set and from 0.917 to 0.922 in the test set. The highest F1-scores were observed for LASSO with CV selection in both the training (0.451) and test sets (0.426). Taken together, the LASSO with CV selection model offered the most balanced predictive performance, showing the highest AUC, PPV, NPV, and F1-score across both datasets. Model calibration was also assessed using Brier scores and calibration plots. All 4 models demonstrated good calibration (Brier scores, 0.049–0.051), with the LASSO-CV model performing best. Calibration plots are shown in Figure S3.

Factors Associated with Suicidal Ideation among Family Members of Persons with Disabilities

Table 3 presents factors associated with suicidal ideation among family members of persons with disabilities in the total sample using 3 analytical approaches: traditional multivariate logistic regression, LASSO regression, and multivariate logistic regression using LASSO-selected variables.

In the traditional multivariate logistic regression model including all 31 variables, 6 factors were statistically significant at the $p < 0.05$ level: depression of family members (coefficient = 0.099, $p < 0.001$), self-esteem of family members (coefficient = −0.086, $p = 0.002$), chronic illness of family members (coefficient = 0.925, $p < 0.001$), suicidal ideation of persons with disabilities (coefficient = 1.283, $p < 0.001$), interfamilial conflict (coefficient = 0.721, $p < 0.001$), and caregiving burden (coefficient = 0.208, $p = 0.009$).

The LASSO regression retained 16 of the original 31 variables. These included sex of family members, age of family members, depression of family members, self-esteem of family members, chronic illness of family members, suicidal ideation of persons with disabilities, age of persons with disabilities, disability acceptance of persons with disabilities, ADL of persons with disabilities, number of family members, family type (spouse), family type (extended family members), beneficiary of national basic livelihood

Table 2. Development of a predictive model for suicidal ideation among family members of persons with disabilities

	Multivariate logistic		LASSO with CV selection		LASSO with adaptive selection		Ridge	
	Training set	Test set	Training set	Test set	Training set	Test set	Training set	Test set
AUC	0.872	0.852	0.875	0.853	0.869	0.848	0.870	0.852
Sensitivity	0.485	0.461	0.487	0.461	0.465	0.438	0.415	0.388
Specificity	0.955	0.948	0.96	0.953	0.958	0.951	0.965	0.957
PPV	0.393	0.371	0.421	0.396	0.397	0.375	0.408	0.377
NPV	0.967	0.963	0.968	0.964	0.966	0.962	0.964	0.959
Accuracy	0.925	0.917	0.93	0.922	0.927	0.919	0.93	0.922
F1-score	0.434	0.411	0.451	0.426	0.428	0.404	0.411	0.382

LASSO, least absolute shrinkage and selection operator; CV, cross-validation; AUC, area under the receiver operating characteristic curve; PPV, positive predictive value; NPV, negative predictive value.

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Table 3. Factors associated with suicidal ideation among family members of persons with disabilities

Variable	Multivariate logistic			LASSO regression		Multivariate logistic using the LASSO-selected variables		
	Coef.	SE	*p*>z	Penalized coef.	Std. coef.	Coef.	SE	*p*>z
Individual characteristics of family members								
Sex of family members (ref. = female)	0.289	0.240	0.228	0.170	0.083	0.325	0.183	0.075
Age of family members	−0.187	0.141	0.185	−0.185	−0.260	−0.275	0.073	0.000
Education level of family members	0.027	0.096	0.780	x	x	-	-	-
Depression of family members	0.099	0.017	0.000	0.085	0.554	0.087	0.016	0.000
Self-esteem of family members	−0.086	0.028	0.002	−0.072	−0.261	−0.085	0.027	0.002
Employment status of family members (ref. = unemployed)	−0.068	0.199	0.734	x	x	-	-	-
Marital status of family members (ref. = single/divorced/ widowed)	−0.402	0.327	0.218	x	x	-	-	-
Chronic illness of family members (ref. = none)	0.925	0.202	0.000	0.752	0.371	0.950	0.199	0.000
Individual characteristics of persons with disabilities								
Suicidal ideation of persons with disabilities (ref. = no)	1.283	0.197	0.000	1.153	0.425	1.217	0.186	0.000
Sex of persons with disabilities (ref. = female)	0.034	0.229	0.883	x	x	-	-	-
Age of persons with disabilities	−0.257	0.142	0.070	−0.117	−0.165	−0.188	0.072	0.010
Depression of persons with disabilities	−0.023	0.016	0.148	x	x	-	-	-
Grade of disability of persons with disabilities	−0.068	0.212	0.749	x	x	-	-	-
Type of disability of persons with disabilities (ref. = external physical disabilities)								
Internal physical disabilities	−0.037	0.220	0.867	x	x	-	-	-
Mental disabilities	0.323	0.331	0.330	x	x	-	-	-
Disability acceptance of persons with disabilities	−0.015	0.019	0.432	−0.001	−0.007	−0.005	0.018	0.767
ADL of persons with disabilities	0.015	0.012	0.210	0.004	0.047	0.009	0.010	0.382
Eating alone (ref. = no)	−0.146	0.200	0.466	x	x	-	-	-
Family characteristics of households with disability								
No. of family members	0.160	0.121	0.186	0.040	0.032	0.125	0.115	0.279
Family type (ref. = ascendant relatives)								
Spouse	0.870	0.484	0.072	0.141	0.069	0.435	0.218	0.046
Descendants	0.293	0.788	0.710	x	x	-	-	-
Extended family members	−0.131	0.592	0.825	−0.102	−0.023	−0.365	0.444	0.411
Beneficiary of national basic livelihood (ref. = no)	0.190	0.241	0.429	0.101	0.035	0.233	0.227	0.305
Log of family income	−0.002	0.025	0.945	x	x	-	-	-
Financial crisis	0.012	0.017	0.491	0.000	0.003	0.006	0.017	0.730
Family strengths	−0.005	0.008	0.539	−0.003	−0.032	−0.006	0.008	0.484
Interfamilial conflict (ref. = no)	0.721	0.192	0.000	0.677	0.310	0.700	0.189	0.000
Caregiving burden	0.208	0.080	0.009	0.177	0.249	0.212	0.078	0.007

(Continued on the next page)

Table 3. Continued

Variable	Multivariate logistic			LASSO regression		Multivariate logistic using the LASSO-selected variables		
	Coef.	SE	*p*>z	Penalized coef.	Std. coef.	Coef.	SE	*p*>z
Social characteristics of households with disability								
Social relationship satisfaction	0.014	0.060	0.810	x	x	-	-	-
Frequency of contact with friends	0.039	0.050	0.431	x	x	-	-	-
Frequency of professional contact	−0.137	0.086	0.113	−0.063	−0.067	0.016	0.056	0.769
Leisure activity companion (ref. = non-participant)						-	-	-
Participates alone	0.227	0.274	0.408	0.117	0.058	0.273	0.183	0.135
Participates with family	−0.085	0.297	0.775	x	x	-	-	-
Participates with acquaintances	0.027	0.438	0.951	x	x	-	-	-
Constants	−2.449	1.461	0.094	−2.888	−3.403	−2.872	1.338	0.032

Variables marked with "x" were excluded from the final prediction model after least absolute shrinkage and selection operator (LASSO) regression.
LASSO, least absolute shrinkage and selection operator; coef., coefficient; SE, standard error; std. coef., standardized coefficient; ref., reference; ADL, activities of daily living; -, variable not included in the model.

status, financial crisis, family strengths, interfamilial conflict, and caregiving burden.

To validate the statistical significance of the LASSO-selected predictors, we conducted a subsequent multivariate logistic regression including only these 16 variables. Among these variables, 8 were statistically significant at the $p < 0.05$ level: depression of family members (coefficient = 0.087, $p < 0.001$), self-esteem of family members (coefficient = −0.085, $p = 0.002$), chronic illness of family members (coefficient = 0.950, $p < 0.001$), suicidal ideation of persons with disabilities (coefficient = 1.217, $p < 0.001$), age of family members (coefficient = −0.275, $p < 0.001$), age of persons with disabilities (coefficient = −0.188, $p = 0.010$), family type—spouse (coefficient = 0.435, $p = 0.046$), interfamilial conflict (coefficient = 0.700, $p < 0.001$), and caregiving burden (coefficient = 0.212, $p = 0.007$).

Factors Associated with Suicidal Ideation among Family Members of Persons with Disabilities: Comparison between Congenital and Acquired Disability

Table 4 presents the results of the LASSO regression analyses identifying factors associated with suicidal ideation among family members of persons with disabilities, stratified by congenital and acquired disability groups.

In the congenital disability group, the LASSO regression retained 10 of the original 31 variables. The selected factors included sex of family members, depression of family members, suicidal ideation of persons with disabilities, age of persons with disabilities, depression of persons with disabilities, eating alone, beneficiary of national basic livelihood status, log of family income, financial crisis, interfamilial conflict, and frequency of professional contact.

In the acquired disability group, the LASSO regression retained 19 of the 31 original variables. These included sex of family members, age of family members, depression of family members, self-esteem of family members, chronic illness of family members, suicidal ideation of persons with disabilities, age of persons with disabilities, internal physical disabilities, mental disabilities, disability acceptance of persons with disabilities, ADL of persons with disabilities, eating alone, number of family members, family type (spouse), family type (extended family members), family strengths, interfamilial conflict, caregiving burden, frequency of professional contact, and leisure activity companion type (participates alone).

Variables with the Strongest Predictive Associations for Suicidal Ideation in Family Members of Persons with Disabilities

Figure 1 presents the 10 variables with the strongest predictive associations for suicidal ideation among family members of persons with disabilities, based on standardized coefficients derived from the LASSO regression analyses. These standardized coefficients reflect relative importance within the regularized predictive model rather than unbiased effect sizes.

In the total sample, the variables showing the strongest predictive associations were depression of family members (β = 0.554), suicidal ideation of persons with disabilities (β = 0.425), chronic illness of family members (β = 0.371), interfamilial conflict (β = 0.310), and self-esteem of family members (β = 0.261). Additional important predictors included age of family members (β = 0.260), caregiving burden (β = 0.249), age of persons with disabilities (β = 0.165),

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Table 4. Factors associated with suicidal ideation among family members of persons with disabilities: comparison between congenital and acquired disability

Variable	Congenital disability		Acquired disability	
	Penalized coef.	Std. coef.	Penalized coef.	Std. coef.
Individual characteristics of family members				
Sex of family members (ref. = female)	0.623	0.309	0.067	0.032
Age of family members	x	x	−0.193	−0.273
Education level of family members	x	x	x	x
Depression of family members	0.055	0.332	0.086	0.562
Self-esteem of family members	x	x	−0.075	−0.270
Employment status of family members (ref. = unemployed)	x	x	x	x
Marital status of family members (ref. = single/divorced/widowed)	x	x	x	x
Chronic illness of family members (ref. = none)	x	x	0.795	0.392
Individual characteristics of persons with disabilities				
Suicidal ideation of persons with disabilities (ref. = no)	1.016	0.321	1.131	0.422
Sex of persons with disabilities (ref. = female)	x	x	x	x
Age of persons with disabilities	−0.016	−0.026	−0.119	−0.156
Depression of persons with disabilities	−0.033	−0.209	x	x
Grade of disability of persons with disabilities	x	x	x	x
Type of disability of persons with disabilities (fef. = external physical disabilities)				
Internal physical disabilities	x	x	−0.018	−0.008
Mental disabilities	x	x	0.077	0.020
Disability acceptance of persons with disabilities	x	x	−0.002	−0.012
ADL of persons with disabilities	x	x	0.008	0.091
Eating alone (ref. = no)	0.124	0.058	−0.006	−0.003
Family characteristics of households with disability				
No. of family members	x	x	0.064	0.052
Family type (ref. = ascendant relatives)				
Spouse	x	x	0.146	0.071
Descendants	x	x	x	x
Extended family members	x	x	−0.316	−0.068
Beneficiary of national basic livelihood (ref. = no)	1.343	0.541	x	x
Log of family income	−0.022	−0.075	x	x
Financial crisis	0.020	0.112	x	x
Family strengths	x	x	−0.006	−0.063
Interfamilial conflict (ref. = no)	1.034	0.488	0.617	0.282
Caregiving burden	x	x	0.158	0.224
Social characteristics of households with disability				
Social relationship satisfaction	x	x	x	x
Frequency of contact with friends	x	x	x	x
Frequency of professional contact	0.046	0.050	−0.099	−0.107
Leisure activity companion (ref. = non-participant)				
Participates alone	x	x	0.154	0.077
Participates with family	x	x	x	x
Participates with acquaintances	x	x	x	x
Constants	−5.238	−3.526	−2.560	−3.387

Variables marked with "x" were excluded from the final prediction model after LASSO regression.
Coef., coefficient; std. coef., standardized coefficient; ref., reference; ADL, activities of daily living.

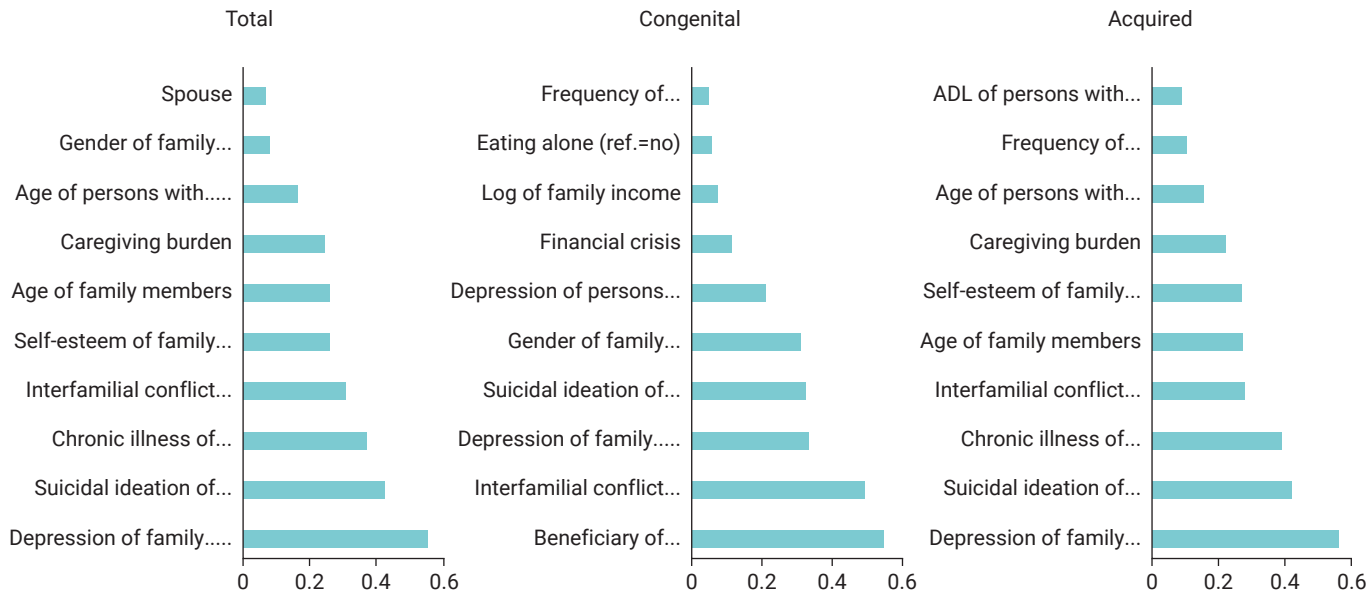


Figure 1. Predictive variables for suicidal ideation in family members of persons with disabilities: standardized coefficients from least absolute shrinkage and selection operator (LASSO) regression. Coefficients represent relative importance for prediction under regularization, not unbiased effect estimates.

sex of family members (β = 0.083), and family type—spouse (β = 0.069).

For the congenital disability group, the variables with the strongest predictive associations were beneficiary of national basic livelihood status (β = 0.541), interfamilial conflict (β = 0.488), depression of family members (β = 0.332), suicidal ideation of persons with disabilities (β = 0.321), and sex of family members (β = 0.309). These were followed by depression of persons with disabilities (β = 0.209), financial crisis (β = 0.112), log of family income (β = 0.075), eating alone (β = 0.058), and frequency of professional contact (β = 0.050).

For the acquired disability group, the variables with the strongest predictive associations were depression of family members (β = 0.562), suicidal ideation of persons with disabilities (β = 0.422), chronic illness of family members (β = 0.392), interfamilial conflict (β = 0.282), and age of family members (β = 0.273). Additional significant predictors included self-esteem of family members (β = 0.270), caregiving burden (β = 0.224), age of persons with disabilities (β = 0.156), frequency of professional contact (β = −0.107), and ADL of persons with disabilities (β = 0.091).

Comparative analysis of shared predictors across groups revealed substantial differences in predictive strength. Interfamilial conflict showed a stronger association in congenital families (β = 0.488) than in acquired families (β = 0.282), whereas depression of family members displayed the opposite pattern, with a stronger association in acquired families (β = 0.562) than in congenital families (β = 0.332). Suicidal ideation of persons with disabilities demonstrated a stronger association in acquired families (β = 0.422) compared with congenital families (β = 0.321). Age of persons with disabilities showed a more pronounced negative association in acquired families (β = −0.156) than in congenital families (β = −0.026). Frequency of professional contact showed a negative association in acquired families (β = −0.107) and a minimal positive association in congenital families (β = 0.050). Sex of family members exhibited a weaker association in acquired families (β = 0.032) than in congenital families (β = 0.309).

Discussion

This study developed machine learning models for predicting suicidal ideation among family members of persons with disabilities using nationally representative DLDP data. Three key findings emerged. First, multivariate logistic regression identified 6 significant predictors, with depression of family members (coefficient = 0.099), suicidal ideation of persons with disabilities (coefficient = 1.283), and chronic illness (coefficient = 0.925) showing strongest associations (all $p < 0.001$). Second, strong evidence of suicide clustering emerged, with disabled persons' suicidal ideation as the second strongest predictor (β = 0.425). Third, stratified analyses revealed distinct patterns by disability onset: economic factors dominated in congenital families (β = 0.541 for national basic livelihood status), while psychological factors were strongest in acquired families

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(β = 0.562 for depression). Shared predictors also showed differential strength, with interfamilial conflict more salient in congenital families and depression stronger in acquired families.

We compared our findings with prior studies examining suicidal ideation in disability populations. The strong predictive role of depression is consistent with previous research conducted in general populations and among disability caregivers [11,14]. However, our results advance this literature by demonstrating that multiple factors—including chronic illness, interfamilial conflict, and caregiving burden—contribute simultaneously to suicide risk. Most notably, the strong association between suicidal ideation among persons with disabilities and their family members (β = 0.425) provides the first empirical evidence of suicide clustering within Korean disability households. Although suicide clustering has been documented in various contexts [30,31], it has rarely been investigated in Asian populations or specifically within disability family systems.

The differential predictive patterns between congenital and families with acquired disability align with theoretical expectations while offering novel empirical validation. Prior research has documented chronic economic strain among families caring for individuals with developmental disabilities and psychological adaptation challenges following the sudden onset of disability [5,18]. Our findings extend this literature by showing that disability onset timing is associated with distinct risk mechanisms requiring tailored intervention strategies. Economic predictors were most prominent among families with congenital disability, consistent with the long-term accumulation of financial and caregiving burdens. In contrast, psychological predictors predominated among families with acquired disability, reflecting acute adjustment crises following unexpected disability onset.

The significance of this investigation is threefold. First, to our knowledge, this is the first study to develop machine learning predictive models for suicidal ideation among family members of persons with disabilities using nationally representative Korean data, achieving superior predictive performance compared with traditional statistical methods. Second, we conducted a comprehensive analysis incorporating 31 variables across individual, family, and social dimensions, offering an integrated understanding that extends beyond single-factor approaches. Third, we empirically demonstrated differential risk patterns between congenital and families with acquired disability, establishing an evidence-based foundation for developing tailored intervention strategies based on disability onset characteristics.

Our findings provide support for multiple theoretical frameworks. The identification of multidimensional predictors aligns with ecological systems theory [23], showing that suicidal ideation among family members results from interactions among individual factors (depression, chronic illness), family factors (interfamilial conflict, caregiving burden), and interpersonal factors (suicidal ideation of persons with disabilities). The strong association between suicidal ideation of persons with disabilities and their family members supports the assortative relation mechanism of suicide clustering by Joiner [31]. Disability families are characterized by geographical proximity, psychosocial closeness, and overlapping stress exposures, creating what Hawton et al. [32] described as circles of vulnerability. The differential patterns between congenital and families with acquired disability are consistent with the stress process model [22], in which congenital disabilities are associated with chronic secondary stressors such as economic hardship, whereas acquired disabilities are associated with acute adaptation responses, including psychological distress.

These findings have direct practice implications. The multidimensional predictive factors indicate need for integrated assessment approaches rather than single-factor screening. Healthcare systems should establish comprehensive frameworks assessing individual, family, and interactive factors simultaneously. The observed clustering effect necessitates family-system–based evaluations rather than separate individual assessments. Our model provides technical foundation for developing such screening instruments.

Differential patterns require tailored interventions by disability onset type. For congenital disability families, prioritize structural interventions addressing economic vulnerabilities: expanding national basic livelihood programs, increasing disability allowances, and developing comprehensive financial support systems. For acquired disability families, emphasize therapeutic interventions focused on psychological adaptation: routine depression screening, immediate counseling access, and specialized adaptation programs for sudden disability onset. The clinical applicability is demonstrated through clear risk hierarchies directly applicable to assessment protocols, with emphasis varying by onset type.

Resource allocation should follow disability-specific sequences. For congenital families: economic support, family conflict mediation, then psychological interventions. For acquired families: psychological support, crisis intervention, then social support mechanisms. Healthcare systems should use these predictive hierarchies to develop risk stratification protocols enabling efficient allocation of intensive services to highest-risk families.

This study has several limitations. First, the cross-sectional design prevents the establishment of causal relationships between variables, particularly regarding the mutual influence processes between persons with disabilities and their family members. Although our machine learning models demonstrated strong predictive accuracy, the identified variables should be interpreted as predictive indicators rather than causal determinants of suicidal ideation. Longitudinal investigations are therefore needed to examine the temporal development of suicide clustering phenomena within disability households. Second, the single-item measurement of suicidal ideation, although standard in national surveys such as Korea National Health and Nutrition Examination Survey, cannot capture the complexity or severity of suicidal thoughts. Despite this limitation, such measures have demonstrated acceptable predictive validity and may reduce respondent burden in vulnerable populations [33]. Third, the relatively smaller sample size for families with congenital disability (n=11,380) compared to families with acquired disability (n=113,403) may have affected the stability of stratified analyses. Fourth, common issues associated with survey-based research, including non-response bias and social desirability bias, cannot be ruled out, and thus the findings should be interpreted with caution. Fifth, this study used 2018 data, which predates the coronavirus disease 2019 pandemic. Although more recent 2023 data are available, substantial participant attrition between waves raised concerns about selection bias, particularly because dropout patterns may correlate with caregiving burden and mental health outcomes. The 2018 data therefore provide more complete pre-pandemic baseline patterns, though future research should examine how pandemic-related stressors may have altered these predictive relationships. Sixth, we did not examine sex concordance between caregivers and persons with disabilities, nor did we assess differential impacts by relationship type (e.g., spouse versus parent caregivers), which may influence caregiving dynamics and associated stress. Future research should explore whether sex-matched or mismatched dyads exhibit different vulnerability patterns. Seventh, although we included social characteristic variables (frequency of professional contact, social relationship satisfaction, leisure activity patterns), these serve as proxy indicators rather than direct measures of structural factors. While professional contact frequency may reflect regional service availability and social satisfaction may approximate community support, these individual-level perceptions cannot capture objective features such as regional service density, geographic accessibility of mental health resources, or disability infrastructure investments. Future studies should incorporate community-level indicators to examine how structural disparities influence suicide risk. Eighth, our findings are based solely on Korean data without external validation. The unique cultural context of Korean disability families—including Confucian caregiving obligations, specific social welfare systems, and culturally embedded stigma patterns—may limit generalizability to other populations. Additionally, temporal validation using different DLDP waves was not feasible because of substantial panel attrition, which may introduce selection bias. Future studies should validate these predictive patterns in other cultural contexts and assess model stability across different time periods. Ninth, although we provided global model interpretability through standardized coefficients and stratified analyses, we did not implement local explainability methods such as Shapley additive explanations or local interpretable model-agnostic explanations that could yield patient-specific risk explanations. These methods, not currently available in Stata's LASSO implementation, would require additional computational frameworks. While our population-level insights are appropriate for policy planning, clinical decision-support tools would benefit from individual-level interpretability in future applications. Tenth, the model's moderate sensitivity likely reflects the inherent difficulty of predicting low base-rate events using distal, population-level predictors, a pattern consistently reported in suicide prediction research [34]. The high specificity suggests that the identified risk profiles remain meaningful for population-level risk stratification and resource allocation. Nevertheless, future research should explore threshold optimization or the incorporation of proximal risk indicators to enhance sensitivity for clinical screening. Finally, although our machine learning approach provided superior predictive accuracy, it has inherent methodological limitations. The LASSO coefficients presented in this study reflect penalized estimates representing relative contribution to prediction under regularization rather than unbiased effect sizes. Because of the shrinkage property of LASSO, these coefficients tend to be smaller than those from traditional regression models and should not be interpreted as measures of actual effect magnitude. Moreover, this approach provides limited insight into complex interaction effects. Despite these limitations, the findings offer the first evidence-based foundation for developing tailored suicide prevention strategies for Korean disability families based on disability onset characteristics. Future research should address these limitations by employing longitudinal study designs and more comprehensive suicide assessment instruments [35].

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Conclusion

This study provides 3 fundamental contributions to understanding suicidal ideation among family members of persons with disabilities. First, the identification of multidimensional predictors demonstrated that suicide risk arises from complex interactions among multiple factors, underscoring the need for integrated assessment approaches. Second, the differential predictive patterns between congenital and families with acquired disability established that disability onset timing is associated with distinct vulnerability pathways requiring tailored prevention strategies. Third, the analysis of the most strongly predictive variables offered strategic guidance for efficient resource allocation based on disability-specific intervention priorities. Together, these findings provide a critical empirical foundation for researchers, mental health professionals, and policymakers to develop evidence-based, targeted interventions for suicide prevention within Korean disability family systems.

Supplementary Material

Figure S1. Receiver operating characteristic (ROC) curves for four predictive models evaluated on the training dataset (70% of total sample): (A) multivariate logistic regression (AUC = 0.872), (B) LASSO with cross-validation (LASSO-CV; AUC = 0.875), (C) LASSO with adaptive selection (LASSO-Adapt; AUC = 0.869), and (D) ridge regression (AUC = 0.870). The diagonal reference line represents random classification (AUC = 0.5). AUC, area under the receiver operating characteristic curve; **Figure S2.** Receiver operating characteristic (ROC) curves for four predictive models evaluated on the independent test dataset (30% of total sample): (A) multivariate logistic regression (AUC = 0.852), (B) LASSO with cross-validation (LASSO-CV; AUC = 0.853), (C) LASSO with adaptive selection (LASSO-Adapt; AUC = 0.848), and (D) ridge regression (AUC = 0.852). The diagonal reference line represents random classification (AUC = 0.5). AUC, area under the receiver operating characteristic curve; **Figure S3.** Calibration plots for predictive models. Calibration plots displaying the relationship between predicted probabilities (x-axis) and observed frequencies (y-axis) for each risk decile in the independent test dataset: (A) multivariate logistic regression (LOGIT), (B) LASSO with cross-validation (LASSO-CV), (C) LASSO with adaptive selection (LASSO-ADAPT), and (D) ridge regression (RIDGE). Each point represents the mean predicted and observed probability for one decile. The diagonal red dashed line indicates perfect calibration. Supplementary data are available at https://doi.org/10.24171/j.phrp.2025.0261.

Notes

Ethics Approval

The survey conducted by the Korea Disabled Persons Development Institute received approval from a Korean public institution's Institutional Review Board (No: P01-2018-09-22-004), and this study was performed in accordance with the principles of the Declaration of Helsinki. The informed consent was waived because of the retrospective nature of this study.

Conflicts of Interest

The author has no conflicts of interest to declare.

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None.

Availability of Data

The datasets generated and/or analyzed during the current study are available in (the Disability Life Panel Survey of Korea) repository, https://koddi.or.kr/stat/html/user/main/main.

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Original Article

Analysis of factors influencing hemorrhagic fever with renal syndrome and its prediction in Weifang, China from 2013 to 2021

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ABSTRACT

Objectives: This study aimed to analyze the epidemiology and trends of hemorrhagic fever with renal syndrome (HFRS) in Weifang, China (2013–2021) and to guide prevention strategies.

Methods: The study examined the prevalence and incidence trends of HFRS in Weifang (2013–2021). Spearman correlation and wavelet analysis were employed to explore variable relationships and their associations with HFRS incidence. Generalized additive models (GAMs) were used to identify key risk factors, while structural equation modeling (SEM) quantified direct and indirect pathways influencing HFRS transmission. Finally, Bayesian time-series models were applied to predict future HFRS risk.

Results: Weifang reported 2,118 HFRS cases, which displayed distinct seasonality. Spearman correlation linked economic factors (gross domestic product [GDP], crop area, grain output, green space) and meteorological factors (temperature, pressure) to incidence ($r > 0.8$). Wavelet analysis identified *Mus musculus* (2013–2016) and *Rattus norvegicus* (2017–2021) as dominant reservoirs, with temperature, precipitation, and humidity correlating with incidence. GAMs revealed a U-shaped relationship between rodent density and HFRS and an inverted U-shaped relationship between temperature (threshold, 11.64 °C) and HFRS. SEM highlighted the direct and indirect effects of climate via rodent density, mirrored by economic factors (e.g., GDP). Bayesian models effectively predicted HFRS (root mean square error, 7.36; mean absolute percentage error, 0.28; $R^2 = 0.65$).

Conclusion: Climate, economic, and anthropogenic factors drive the spread of HFRS. Prevention strategies should integrate local economic conditions with meteorological and anthropogenic factors. Bayesian time-series modeling effectively predicts HFRS trends, supporting precision prevention strategies.

Keywords: Bayes theorem; Hemorrhagic fever with renal syndrome; Meteorological concepts; Rodentia

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Introduction

Background

Hemorrhagic fever with renal syndrome (HFRS), also known as epidemic hemorrhagic fever, is an important infectious disease caused by hantavirus infection and transmitted by rodents, posing a serious threat to human health [1]. Rodents are the main hosts of hantaviruses [2]. Hantavirus is transmitted to humans primarily through inhalation of aerosols from the urine, feces, and saliva of infected rodents [3] and can also be transmitted through the digestive tract and via direct contact [4]. Clinical symptoms of HFRS include fever, hemorrhage, headache, and renal impairment, with the course of a typical case divided into 5 stages: fever, hypotensive shock, oliguria, polyuria, and recovery [5,6].

In recent years, an estimated 200,000 people worldwide have been affected by HFRS each year [7]. Cases are distributed largely in Asia and Europe, with China reporting the highest number and accounting for 90% of global cases [8]. Moreover, cases have been reported in 31 of 34 provinces, autonomous regions, municipalities, or special administrative regions in China [9]. Shandong Province is among the provinces with the highest number of HFRS cases in China [10]. Weifang, one source of HFRS in Shandong Province, has seen a gradual expansion of affected areas since the first case was reported in 1974 and now represents a high-incidence region for the disease [11].

The prevalence of HFRS is influenced by multiple factors, including socioeconomic conditions, healthcare availability, and the ecological environment [12]. Meteorological conditions play a crucial role in HFRS transmission, particularly through effects on crop growth, hantavirus activity, and daily human behaviors. Precipitation and temperature are key determinants of HFRS incidence. Specifically, precipitation influences vegetation growth and hantavirus spread, which in turn affects transmission. Additionally, temperature fluctuations can impact rodent populations, influencing their reproductive cycles and maturity [13].

Ecological factors also contribute significantly to the spread of HFRS by altering rodent population density, geographic distribution, and the virus carriage rate among these animals [14]. Furthermore, a nonlinear relationship has been observed between the normalized difference vegetation index (NDVI) and HFRS risk. Extremes in NDVI, whether high or low, can affect rodent survival, which subsequently influences the risk of disease transmission to humans [15].

Current research on HFRS determinants has mostly focused on host animals, climate conditions, or their combination. Few studies have integrated host, climate, and economic factors in a comprehensive analysis. For example, previous exploration of HFRS in Weifang has focused mainly on epidemiological characteristics and the impact of climate change on HFRS [16], with relatively scarce research examining economic and ecological factors. On this basis, the present study uses wavelet analysis [17], a generalized additive model (GAM), and structural equation modeling (SEM) to investigate economic, ecological, and climatic factors associated with HFRS in Weifang, Shandong Province, from 2013–2021; to explore the incidence of HFRS; and to predict the timing of cases, thereby providing a theoretical basis for accurate prevention and control measures.

HIGHLIGHTS

- Climate and economic factors jointly drive the spread of hemorrhagic fever with renal syndrome, necessitating combined prevention strategies.
- A shift in the primary host species requires adaptive rodent control measures.
- A Bayesian model accurately forecasts outbreaks, enabling proactive public health interventions.

Materials and Methods

Study Area

Weifang is a prefecture-level city under the jurisdiction of Shandong Province, China. Located in the central part of the Shandong Peninsula, it has a warm temperate, monsoon-influenced, semi-humid continental climate. The topography rises from north to south, with a total area of 16,167.23 square kilometers. As of 2022, the city has jurisdiction over 4 districts and 2 counties and administers 6 county-level cities. At the end of 2023, the permanent population of Weifang was 9.3695 million, with a regional gross domestic product (R. GDP) of 760.601 billion yuan.

Data Collection

HFRS incidence and rodent density

All cases of HFRS in Weifang from January 1, 2013, to December 31, 2021, were obtained from the National Disease Surveillance System of the Chinese Center for Disease Control and Prevention. The dataset included key variables such as gender, age, population classification, current address, case classification, and date of onset. Rodent population monitoring information included the number of effective traps, the number of rodents captured, and rodent species. Rodent density was calculated as (number of

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rodents captured/number of active traps)×100%. Data from 2017 onward were available as monthly figures.

Data processing and interpolation

To ensure consistency in temporal resolution across the study period (2013–2021), we applied data interpolation methods to address differences in time granularity. For rodent density data prior to 2017, which were available at a lower temporal resolution (e.g., quarterly or annually), we used the adjacent midpoint method to interpolate monthly values. The interpolation formula was: missing value = (previous valid value+next valid value)/2.

This approach allowed us to generate monthly estimates for rodent density from 2013 to 2016, ensuring compatibility with the monthly data available from 2017 onward. Similarly, for other variables with inconsistent temporal resolutions, we applied the same interpolation method to maintain uniformity in the dataset. This preprocessing step enabled continuous time-series analyses, including GAM and wavelet analysis, without introducing biases due to temporal mismatches [18].

Meteorological Data

Meteorological data were obtained from the China Meteorological Science Data Sharing Service Network (https://data.cma.cn/). The data included monthly average temperature (tmean, °C), monthly minimum temperature (tmin, °C), monthly maximum temperature (tmax, °C), monthly average precipitation (Ap, mm), monthly average relative humidity (Rh, %), and monthly average wind speed (Ff, m/s). Population size and R. GDP indicators were obtained from the Weifang Statistical Yearbook (http://tjj.weifang.gov.cn/). These data included population (×10³), R. GDP (billion yuan), total grain output (10,000 tons), and other economic indicators (Table 1).

Data Analysis

In this study, a GAM was used to examine the associations between HFRS incidence and rodent density, temperature, Rh, precipitation, population, gross regional product, and total food production. Because HFRS is a low-incidence condition and therefore represents a small-probability event, a Poisson link function was applied to account for the discrete nature of the data. The generalized cross-validation (GCV) index was used as the model selection criterion, with a lower GCV value indicating a better-fitting model. To ensure that the distribution of the response variable approximated a normal distribution, the variable was log-transformed. The optimal model was established as follows:

$$\log[Y_i] = \beta_0 + f_1(tmean_i) + f_2(\log\ yield_{i-1}) + f_3(Rh_i) + f_4(\log\ Average\ rodent\ density_i) + \varepsilon_i,$$

where Y_i is the number of HFRS cases in month i; β_0 is the model intercept; $tmean_i$ is the average temperature in month i; $yield_{i-1}$ is the previous month's total grain yield; Rh_i is the average Rh in month i; $Average.rodent\ density_i$ is the average rodent density in month i; ε_i is the random error term; and f_1, f_2, f_3, and f_4 are natural spline smoothing functions, each with 4 degrees of freedom.

This study used a Bayesian time-series model to predict the incidence of HFRS. The Bayesian method is a statistical inference approach that integrates prior information with observed data to update beliefs and make predictions, offering improved flexibility and adaptability. Similar Bayesian and artificial intelligence-based approaches have been successfully applied to predict infectious disease trends, demonstrating their effectiveness in epidemiological forecasting [19]. Prior to analysis, the dataset was divided into a training set (January 2013–December 2019) and a testing

Table 1. Descriptions of variables and parameters used in the study

Variable	Symbol/abbreviation	Meaning
HFRS cases (*n*)	Y_i	No. of HFRS cases in month i
Population (×10³)	Population	Permanent residents of Weifang
Regional GDP (Billion yuan)	GDP	Weifang regional gross domestic product
Total grain output (10,000 tons)	$Yield_i$	Weifang's grain production in the i-month period
Rodent density (%)	Rodent density	Total number of captures (individuals)/no. of active traps (clips)×100%
Monthly average temperature (℃)	$tmean_i$	Average temperature for the i-th month
Monthly minimum temperature (℃)	$tmin_i$	Minimum temperature in the i-th month
Monthly maximum temperature (℃)	$tmax_i$	Highest temperature in the i-th month
Monthly average precipitation (mm)	Ap_i	Average precipitation for the i-th month
Monthly average relative humidity (%)	Rh_i	Average relative humidity for the i-th month
Monthly average wind speed (m/s)	Ff	Average wind speed for the i-th month

HFRS, hemorrhagic fever with renal syndrome; GDP, gross domestic product.

set (January 2020–December 2021) to validate model fit and assess predictive performance. A key advantage of this model is its reliance on probability distributions rather than point estimates, which promotes adaptability and mitigates the risk of overfitting. Common indicators for assessing model fit include root mean square error (RMSE), mean absolute percentage error (MAPE), and the coefficient of determination (R^2), with smaller RMSE and MAPE values indicating better fit, whereas a larger R^2 value is preferable. By incorporating prior information, the Bayesian method demonstrates greater flexibility and adaptability than traditional approaches.

SEM was then applied to explore the associations of the number of HFRS cases with mean rodent density, climate (tmean and Rh), and economy (yield). Model fit was assessed using the comparative fit index (CFI) and RMSE of approximation (RMSEA). The CFI ranges from 0 to 1, with higher values indicating better model fit; an RMSEA value closer to 0 also indicates better fit.

All statistical analyses were performed with the "biwavelet," "mgcv," "CausalImpact," "lavaan," and "corrplot" packages in R ver. 4.2.1 (R Foundation for Statistical Computing). The confidence intervals (CIs) for all 2-sided statistical tests were 95%.

Results

Descriptive Data

Weifang had 2,118 recorded HFRS cases from January 2013 to December 2021. The highest number of cases was reported in 2013, totaling 388. Among all cases, the number of male patients (n=1,442) was significantly greater than that of female patients (n=523), with a male-to-female ratio of 2.76:1. The age at HFRS onset was most frequently 40 to 69 years, accounting for 69.1% of all cases. The most affected occupational groups included farmers, workers, and students, with farmers (1,726) accounting for 87.8% (Table 2). The trend in HFRS incidence in Weifang from 2013–2021 showed a rapid decline from 2013–2016, followed by a brief period of stability between 2017 and 2018. This was followed by a downward trend from 2019–2020, with a slight increase in cases observed in 2021. Notably, the lowest number of cases was recorded in 2020. Rodent density closely mirrored the trend for HFRS incidence. Additionally, the overall incidence exhibited significant seasonality, with lower counts observed from July to September and peak cases between October and December (Figure 1). The distributions of monthly minimum temperature, Rh, and precipitation exhibited clear cyclical and seasonal patterns (Figure 2), with mean monthly minimum temperature, Rh, and precipitation of 9.65 °C, 62.37%, and 54.24 mm, respectively.

Multivariate Correlation Analysis

Multivariate correlation analysis revealed that, among economic factors, GDP, crop cultivated area, total grain production, and green space area were highly correlated (r>0.8). Mean air temperature, minimum air temperature, maximum air temperature, and air pressure also exhibited high correlations (r>0.8). Mean rodent density was correlated (r>0.5) with the densities of brown rats and small house mice (Figure 2).

Wavelet Correlation between HFRS and Rodent Density

Wavelet analysis indicated a correlation between HFRS incidence and the population density of small house mice from 2013–2016 and a correlation between HFRS incidence

Table 2. Characteristics of HFRS cases in Weifang, 2013–2021

Variable	No. of HFRS cases	Component ratio (%)	x^2/F	p
Sex			10.325 (x^2)	<0.01
Male	1,442	73.38		
Female	523	26.62		
Age (y)			12.545 (F)	<0.01
0–39	469	23.87		
40–69	1,358	69.11		
≥70	138	7.02		
Occupation			15.540 (F)	<0.01
Farmer	1,726	87.84		
Worker	129	6.56		
Student	51	2.60		
Others	59	3.00		
Total	2,118	100.00		

HFRS, hemorrhagic fever with renal syndrome.

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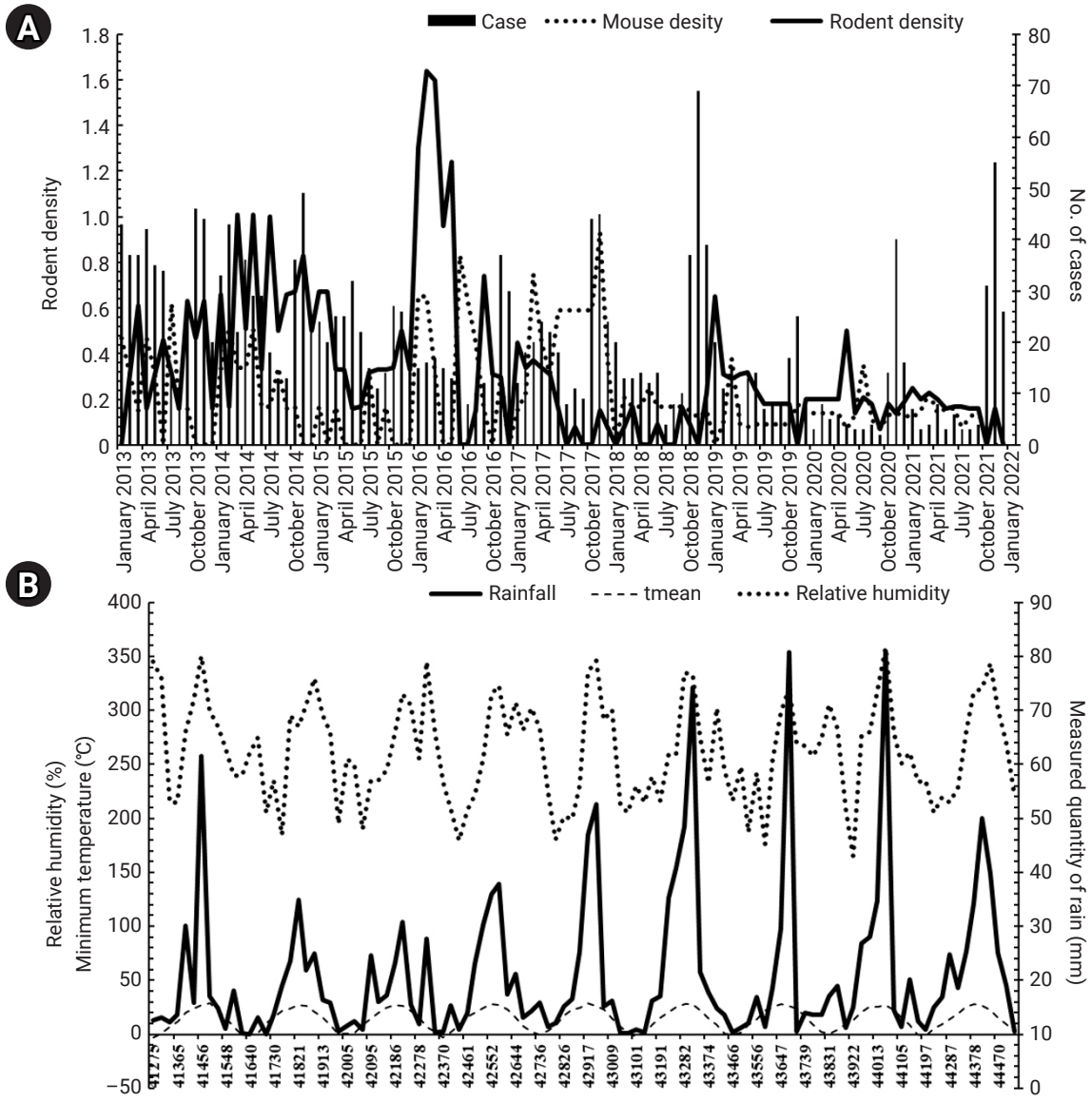


Figure 1. Dynamic associations between hemorrhagic fever with renal syndrome (HFRS) incidence, rodent density, and meteorological factors in Weifang from 2013 to 2021. (A) Incidence of HFRS and trends in rodent density in Weifang. (B) Temporal changes in meteorological variables in Weifang. tmean, monthly average temperature.

and the population density of brown rats from 2017–2021 (Figure 3). The occurrence of HFRS can be divided into 2 phases: 2013–2016, when the main hosts were small house mice, and 2017–2021, when the main hosts were brown rats.

HFRS Incidence in Relation to Climate and Economy

The GAM analysis revealed a positive correlation between monthly average rodent density and HFRS incidence, indicating that higher rodent density significantly increases the risk of HFRS outbreaks. Regarding meteorological factors, both monthly mean temperature (tmean) and monthly mean Rh exhibited nonlinear associations with HFRS incidence, specifically U-shaped relationships with distinct inflection points at approximately 11.64 °C for temperature and 68.31% for humidity. Below these thresholds, the factors were positively correlated with incidence, whereas above them, the correlations became negative.

The nonlinear relationships between these key predictors—tmean, Rh, and average rodent density—and HFRS incidence are shown in Figure 4 through GAM smoothing curves. Temperature displayed a U-shaped relationship with incidence, peaking near 11.64 °C; Rh showed an inverted U-shaped pattern, peaking around 68.31%; and average rodent density maintained a consistent positive linear

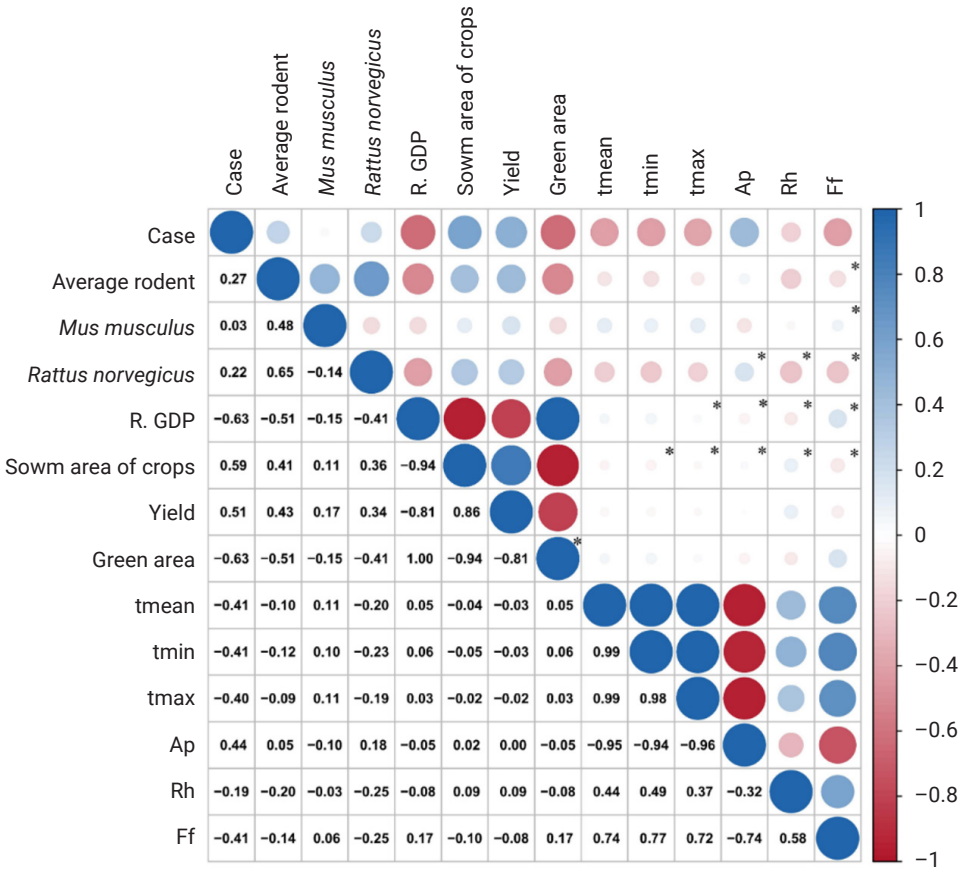


Figure 2. Correlation analysis diagram.
R. GDP, regional gross domestic product; tmean, monthly average temperature (°C); tmin, monthly minimum temperature (°C); tmax, monthly maximum temperature (°C); Ap, monthly average precipitation (mm); Rh, monthly average relative humidity (%); Ff, monthly average wind speed (m/s).
*p<0.05 (Statistically significant difference).

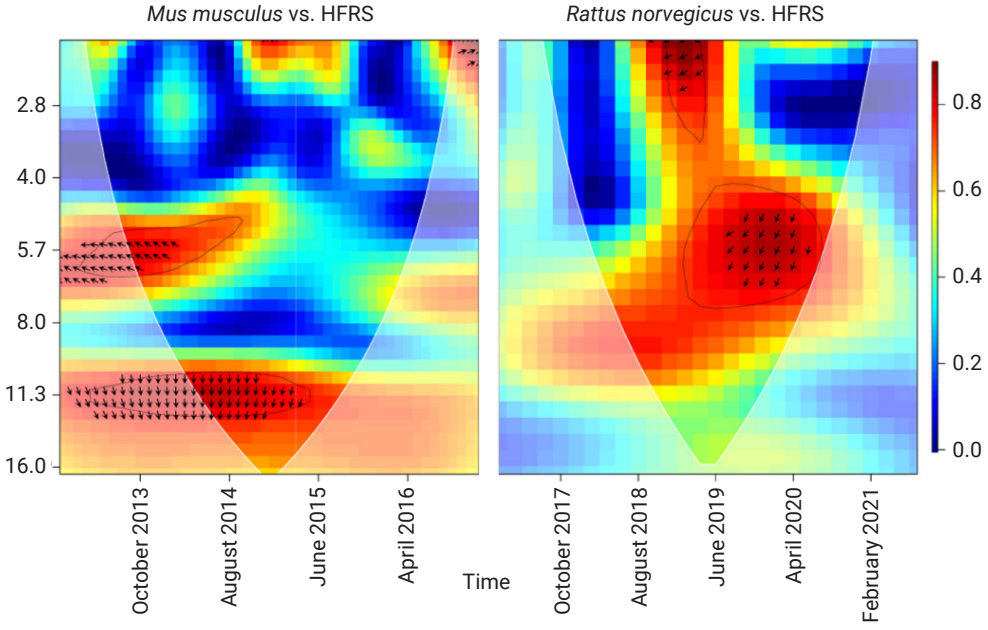


Figure 3. Wavelet correlation between the incidence of hemorrhagic fever with renal syndrome (HFRS) and the densities of small house mice (*Mus musculus*) and brown rats (*Rattus norvegicus*).

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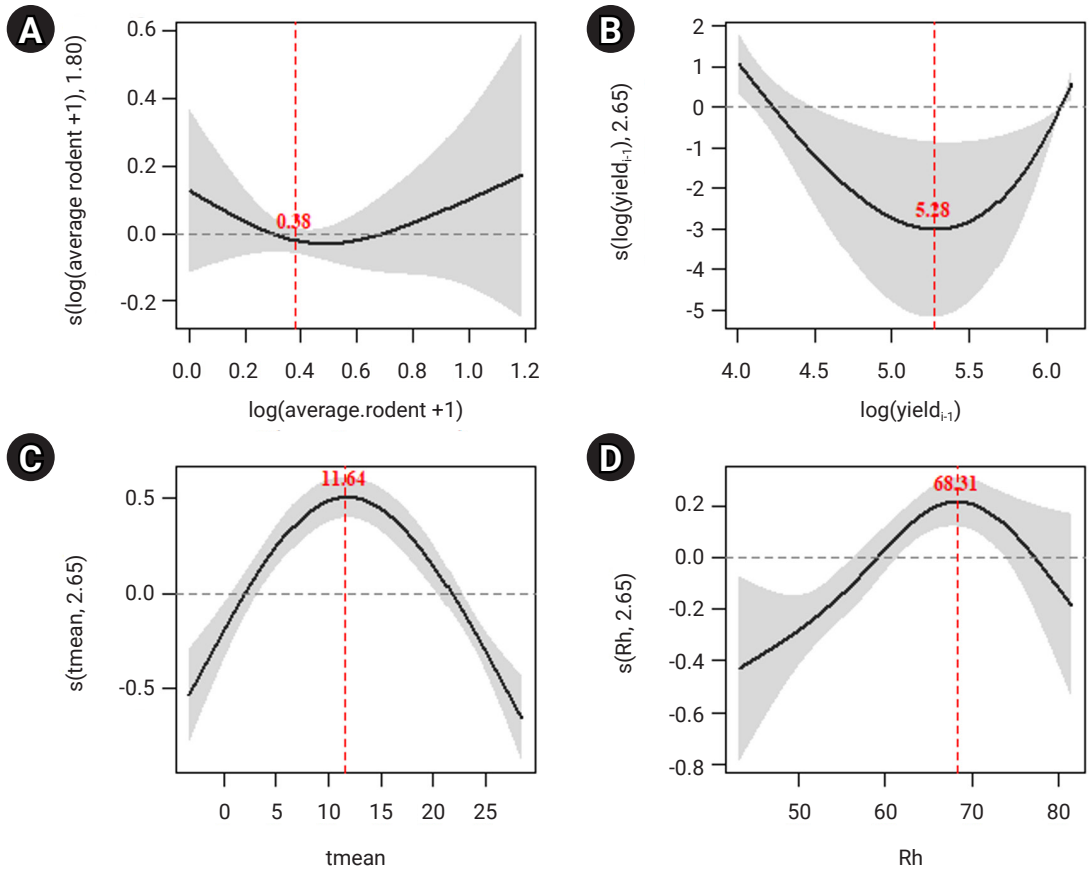


Figure 4. Effects of temperature, relative humidity, and rodent density on the incidence of hemorrhagic fever with renal syndrome (HFRS). The y-axis represents the smooth function on the log scale (log relative risk). Centered smooth terms indicate the contribution of each variable to the log-expected case count. The shaded area represents the 95% confidence interval. (A) Relationship between average rodent population and HFRS incidence. (B) Relationship between previous month's total grain production and HFRS incidence. (C) Relationship between monthly average temperature and HFRS incidence. (D) Relationship between monthly average relative humidity and HFRS incidence.
tmin, monthly minimum temperature (℃); Rh, monthly average relative humidity (%).

Table 3. Effects of influencing factors on hemorrhagic fever with renal syndrome risk

	Average rodent density	tmean	Rh	Yield$_{i-1}$
RR	0.94	2.09	1.28	0.54
95% CI	0.78–1.13	1.51–2.88	0.95–1.75	0.24–119.07

tmean, monthly average temperature; Rh, monthly average relative humidity; RR, risk ratio; CI, confidence interval.

correlation. These findings corroborate the statistical model results presented in Table 3, further validating the model. With respect to economic factors, a clear inflection point was observed between the previous month's total grain yield ($yield_{i-1}$) and HFRS incidence, characterized by an initial negative correlation followed by a positive correlation beyond the inflection point, forming a U-shaped relationship (Figure 4). Regarding risk ratios (RRs), the RR for monthly average rodent density was 0.94 (95% CI, 0.78–1.13); for tmean, 2.09 (95% CI, 1.51–2.88); for monthly average Rh, 1.28 (95% CI, 0.95–1.75); and for the previous month's total grain yield, 0.54 (95% CI, 0.24–119.07). All estimates are summarized in Table 3.

The Bayesian Prediction Model

The factors influencing HFRS occurrence identified above (average rodent density, tmean, Rh, and $yield_{i-1}$) were incorporated into the Bayesian prediction model. The model's fitting performance is illustrated in Figure 5, where the triangular dashed line represents the actual number

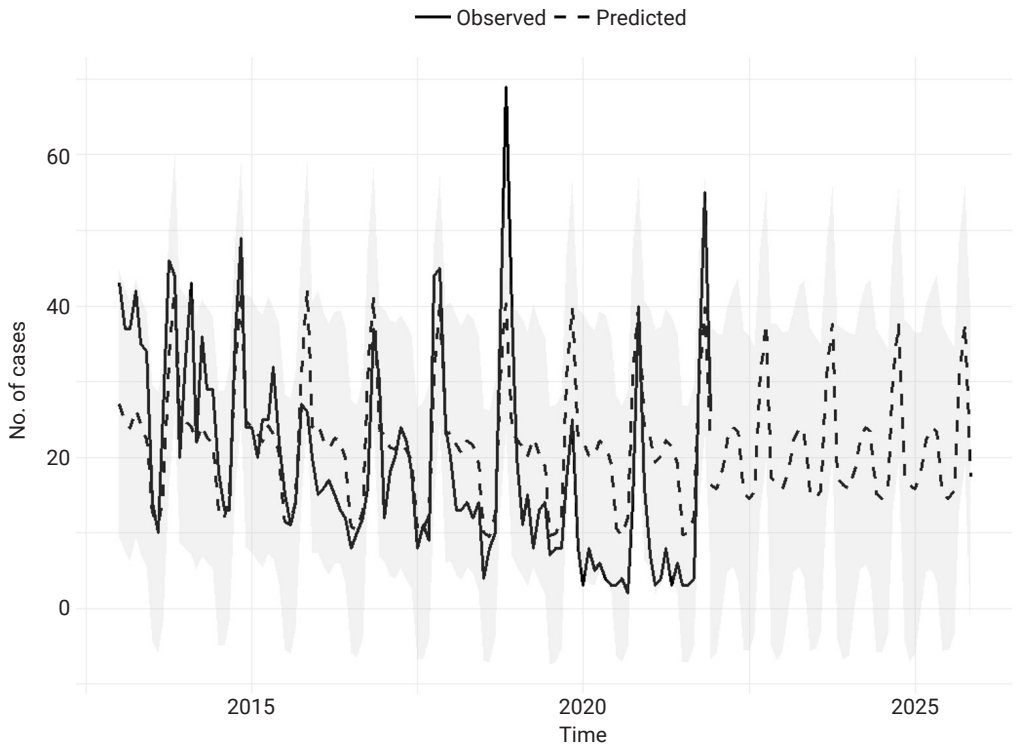


Figure 5. Comparison of monthly reported hemorrhagic fever with renal syndrome cases in Weifang with fitted generalized additive model values.

of cases, the solid square line represents the predicted values, and the shaded area indicates the 95% CI. Notably, the predicted values closely aligned with the observed data, demonstrating a strong model fit. The validation results confirmed that the established model accurately predicted HFRS occurrence in Weifang during 2020–2021, with performance metrics of RMSE = 7.36, MAPE = 0.28, and R^2 = 0.65.

Pathways Influencing HFRS Incidence

The SEM results clarify the pathways influencing HFRS occurrence. As shown in Figure 6, the latent variable "climate" (comprising Rh, average temperature, and rainfall) exerted a positive effect on average rodent density (path coefficient, +0.698). Conversely, the direct path from climate to HFRS incidence had a negative coefficient (−0.402). The direct paths from R. GDP and average rodent density to HFRS were also negative, with coefficients of −0.650 and −0.093, respectively.

Discussion

Prevalence of HFRS

A total of 2,118 cases of HFRS were reported in Weifang from 2013 to 2021. Overall, reported cases displayed a general downward trend, with a rebound observed in 2017. This finding may relate to climate change, shifts in rodent habitat, and population vaccination coverage. Among reported HFRS cases, the number of male patients was significantly higher than that of female patients. The age of onset was predominantly 40 to 69 years, and farmers were the most affected occupational group, aligning with prior studies [19]. This pattern may be explained by the greater likelihood of adult males to be exposed to infected rodents through occupational activities. Related occupations, such as herding, also face an increased risk of infection [20].

Shift in Primary Host Animal

In Weifang, mice were the primary animal hosts of HFRS from 2013–2016; however, brown rats became the dominant host species from 2017–2021. This shift may be associated with the city's urban–rural development during that period, including the urbanization of rural areas and the renovation of rural toilets and household sewage systems. Such human activities can alter community structure, species distribution, and the population density of host animals. Urbanization processes influence ecological quality and dynamics at different stages of development [21], thereby modifying vector populations and transmission patterns. Additionally, the significant decrease in total grain production after 2017 may

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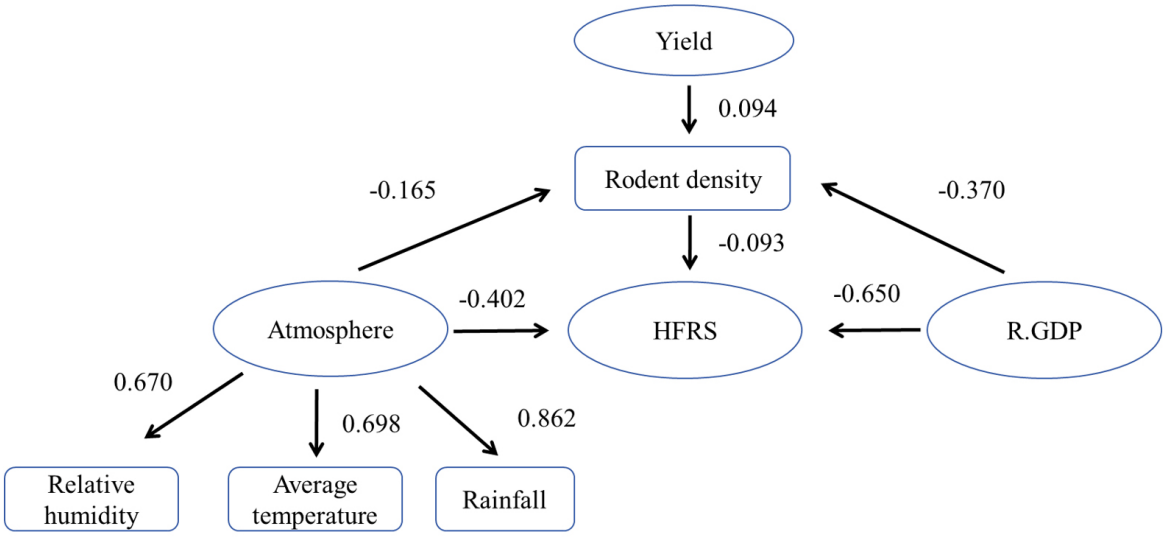


Figure 6. Path analysis of ecological, climatic, and economic effects on the incidence of hemorrhagic fever with renal syndrome (HFRS). R. GDP, regional gross domestic product.

have further contributed to this shift in host species. Beyond environmental changes, improvements in living conditions driven by economic development have also impacted host habitats and influenced population dynamics [22]. A GAM analysis demonstrated that rodent density, temperature, Rh, and total grain yield significantly affected the prevalence of HFRS, further supporting our observations.

Potential Drivers of Seasonal Incidence Pattern

Weifang exhibits pronounced seasonal variations in HFRS incidence, with peak cases occurring annually from October to December and relatively low incidence from July to September. This epidemiological pattern likely results from the combined influence of agricultural cycles, rodent ecology, and human activities. The autumn harvest season (October–December) represents a critical period of heightened risk. First, large-scale grain harvesting and storage provide abundant food sources for rodents, leading to rapid population growth and increased proximity to human dwellings. Second, declining temperatures drive rodents—such as the black-striped field mouse—to migrate from fields into warmer indoor environments such as houses and granaries, substantially increasing human exposure to virus-contaminated excreta. At the same time, concentrated indoor grain processing following the harvest further elevates the risk of aerosol transmission within enclosed spaces [23]. In contrast, incidence levels are lower during the summer months (July–September). Agricultural activities at this time focus primarily on field management, with rodents widely dispersed across open terrain, markedly reducing opportunities for human-rodent contact.

Influence of Climatic Factors on the Incidence of HFRS

This study employed SEM to elucidate the pathways through which climatic factors influence the incidence of HFRS. As shown in Figure 6, the latent variable "Atmosphere" (comprising Rh, average temperature, and rainfall) demonstrated a weak positive indirect effect on HFRS through rodent density: the path coefficient from Atmosphere to rodent density was −0.165 and that from rodent density to HFRS was −0.093, yielding an indirect effect of approximately +0.015. This finding aligns with established ecological mechanisms in which moderate climatic conditions promote rodent population growth, thereby indirectly increasing transmission risk, consistent with observations from Weifang [24]. However, the direct path from Atmosphere to HFRS had a negative coefficient (−0.402), which may reflect residual effects after controlling for rodent density or limitations in capturing complex climatic interactions due to data constraints. This provides a plausible explanation for inconsistencies across studies: for instance, our results partially align with those of Lin et al. [25], whereas Li et al. [26] reported a persistent negative correlation between temperature and HFRS, potentially attributable to regional variations in climatic conditions and human behavior. Temperature primarily affects HFRS by modifying rodent habitat and activity, with an optimal reproductive range of 10–25 °C [11]; however, extreme temperatures may directly reduce human outdoor exposure. Regarding humidity, a nonlinear relationship with HFRS was observed—positive below the

68.31% Rh threshold but negative above it—consistent with the findings of Xiao et al. [27,28] and Liang et al. [29]. This suggests that moderate humidity increases rodent density, whereas excessive rainfall disrupts habitats. Additionally, R. GDP exhibited a strong direct inhibitory effect on HFRS (path coefficient, −0.650), underscoring the influence of socioeconomic factors in disease control. In summary, the SEM results indicate that the indirect climatic effect via rodents, although modest, is positive, whereas the direct negative path warrants further investigation into residual or confounding mechanisms.

Influence of the Economy on HFRS Incidence

The present study revealed a nonlinear relationship between the previous month's total grain yield and the number of HFRS cases. A turning point was observed in total grain production, with the correlation initially negative and becoming positive beyond that point. This study also found that economic development is negatively associated with the incidence of HFRS, consistent with the findings of Xiao et al. [27]. Previous research has shown that economic development plays important roles in the occurrence, spread, prevention, and control of infectious diseases [30]. This finding supports broader evidence that socioeconomic factors interact with meteorological conditions to influence disease transmission patterns. Rapid economic development has substantially improved living conditions and hygiene, reducing the likelihood of human contact with rodents and thus lowering the risk of HFRS. In addition, increased public awareness of the disease further contributes to limiting its spread.

Modeling of the Prediction of HFRS Onset Time

The model's predictions closely aligned with observations at multiple time points, accurately capturing fluctuations in case counts and reflecting the dynamic behavior of HFRS incidence. We project that, assuming other conditions remain unchanged, HFRS incidence will continue to exhibit periodic fluctuations in the coming years. Discrepancies between predicted and observed values at certain time points may arise from the model's inability to fully account for the complex factors influencing HFRS incidence, including spatial heterogeneity and external shocks. Future research should consider incorporating additional factors to increase the predictive accuracy and undertake model optimization and validation to ensure robustness across regions and time periods. Model adjustments may also be necessary to better accommodate the complexity and uncertainty of HFRS incidence at specific time points.

Although this study provides a comprehensive analysis of the HFRS epidemic using multiple epidemiological and statistical methods, several limitations remain. For example, because it focuses on a single city (Weifang), its representativeness is limited, and it lacks comparative analysis with other regions. This limitation may affect the broader applicability of the findings. Moreover, the research's focus on Weifang without incorporating a wider regional perspective may further limit the generalizability of the results. In addition, although the Bayesian time-series model demonstrated strong predictive performance, it did not include spatial factors in the analysis. Future studies could improve predictive accuracy and model applicability by expanding the scope of data collection, integrating dynamic monitoring of host behavior and environmental factors, and adopting other innovative approaches.

Conclusion

In summary, the spread of HFRS is driven by multiple factors, including climatic and meteorological conditions, economic influences, and human activities. To effectively prevent and control outbreaks, targeted measures should be tailored to local circumstances. For example, during the peak incidence season from October to December, Weifang should strengthen surveillance and prevention efforts, particularly in managing the brown rat population.

Notes

Ethics Approval

Not applicable.

Conflicts of Interest

The authors have no conflicts of interest to declare.

Funding

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Availability of Data

The datasets analyzed in this study are available from the National Disease Surveillance System of the Chinese Center for Disease Control and Prevention (CDC), the Ministry of Ecology and Environment of the People's Republic of China, and the China Meteorological Science Data Sharing Service Network; however, restrictions apply. These datasets were used under license for the present study and are not publicly available. They may be requested from the corresponding author, who will facilitate contact with the respective organizations.

Authors' Contributions

Conceptualization: HZ; Data curation: HZ, XYG, YHS; Formal analysis: WYZ, YQY; Funding acquisition: JL, QYL; Investigation: HZ, WYZ; Methodology: HZ, WYZ; Project administration: JL, QYL, YQY; Resources: XYG, YHS; Software: HZ, WYZ; Supervision: JL, QYL, YQY; Validation:

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WHW, XYG, YHS; Visualization: XYG, YHS; Writing–original draft: HZ; Writing–review & editing: all authors. All authors read and approved the final manuscript.

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Short Communication

Early detection of dengue through rapid diagnostic testing at airport quarantine: a case study from the Republic of Korea (2022–2024)

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ABSTRACT

Objectives: This study evaluated the effectiveness of rapid diagnostic testing (RDT) for the early detection of imported dengue cases at Gimhae International Airport in the Republic of Korea, and analyzed patient characteristics and response processes following positive results.
Methods: From 2022 to 2024, 334 individuals underwent RDT at the airport. Testing was performed for travelers presenting with dengue-like symptoms or recent mosquito bites. Two dengue RDT kits (NS1 and immunoglobulin G/M) were used, and confirmatory tests—including real-time reverse transcription polymerase chain reaction and enzyme-linked immunosorbent assays—were performed for RDT-positive cases. Time intervals between sample collection and diagnostic confirmation were compared by institution type and day of the week.
Results: Of the 334 cases tested, 12 yielded positive RDT results, and 3 were confirmed as dengue. No confirmed cases were identified among asymptomatic travelers or those with travel durations shorter than 5 days. All 3 confirmed cases showed moderate or higher RDT intensity. The confirmatory results were negative for all 7 marginally positive cases. The average turnaround time for diagnostic confirmation was 4.00 days in hospitals versus 2.71 days in public health centers. Samples collected on weekdays produced faster results (2.33 days) than those collected across weekends (5.00 days). One individual with a strong RDT-positive result declined confirmatory testing.
Conclusion: RDT is a valuable tool for detecting dengue at ports of entry. However, timely confirmatory diagnosis requires improved inter-agency coordination and logistical systems, particularly for weekend operations. These findings offer practical insights for strengthening quarantine-based infectious disease control.

Keywords: Dengue; Quarantine; Rapid diagnostic tests

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Introduction

Dengue is a vector-borne viral disease transmitted mainly by *Aedes aegypti* and *Aedes albopictus* mosquitoes [1]. Driven by climate change and globalization, nearly half of the world's population is now at risk of infection. Increased international travel has significantly contributed to the global spread of the dengue virus [2]. In 2014, a major outbreak occurred in Japan after a traveler returning from a dengue-endemic country introduced the virus, leading to local transmission and 160 infections [3]. In the Republic of Korea, 100 to 200 imported dengue cases are reported each year, highlighting the importance of rigorous entry-point surveillance [4]. To prevent domestic introduction, the Korea Disease Control and Prevention Agency (KDCA) has implemented a series of countermeasures. On December 1, 2023, dengue was formally designated a quarantinable infectious disease, further strengthening surveillance and early detection systems [5]. While several studies have examined dengue surveillance at entry points, no research has investigated patient characteristics and response processes spanning from the initial detection of suspected cases to final confirmation [6–8]. This study therefore analyzes the characteristics and response procedures of dengue rapid diagnostic testing (RDT) cases detected at Gimhae International Airport between 2022 and 2024. The airport manages approximately 10,000 flights and 15 million passengers annually, making it a critical site for monitoring imported infections. The findings aim to provide practical insights for enhancing quarantine operations in the future.

HIGHLIGHTS

- This study analyzed 334 cases of rapid diagnostic testing (RDT) for dengue conducted at Gimhae International Airport from 2022 to 2024.
- Of the 12 RDT-positive cases, 3 were confirmed as dengue, all of which showed moderate or higher RDT intensity.
- Delays in confirmatory diagnostics were observed, particularly on weekends and in hospital-based testing.
- Strengthening coordination between quarantine authorities and medical institutions may enhance the timeliness of diagnosing imported dengue cases.

Materials and Methods

Study Design

From July 1, 2022, to December 31, 2024, a total of 334 travelers who entered the Republic of Korea through Gimhae International Airport after visiting dengue-designated quarantine regions and underwent RDT were included in this study. The study population comprised individuals subject to mandatory testing under public health regulations as well as those who voluntarily requested testing. All participants provided informed consent for dengue RDT. Mandatory testing was applied to travelers with a history of mosquito bites during their trip who presented with dengue-related symptoms—such as fever, headache, or rash—at the time of entry. These individuals were classified as suspected dengue cases. In contrast, voluntary testers were those who, either at the time of entry or within 7 days thereafter, experienced mosquito bites or dengue-like symptoms and requested testing on their own initiative.

RDT for Dengue

Two commercial kits were used: Asan Easy Test Dengue NS1 Ag and Asan Easy Test Dengue immunoglobulin (Ig) G/IgM (Asan Pharm Co., Ltd.). These kits detect the DENV NS1 antigen (sensitivity, 97.16%; specificity, >99.9%) and IgG/IgM antibodies (IgG sensitivity, 98.29%; IgG specificity, 97.76%; IgM sensitivity, 97.92%; IgM specificity, 100%) in serum samples. For the procedure, whole blood was collected from the fingertip using a lancet. Approximately 100 µL (3 drops) of blood was then applied to the test kit directly or with a disposable dropper. After 15 to 20 minutes, the results were interpreted. A test was considered negative if a color band appeared only on the control line (C), and positive if color bands appeared on both the control line (C) and the test line (T). All procedures followed the manufacturer's instructions.

Traveler Dengue Virus Testing Procedure

At the quarantine station, travelers with positive RDT results were directed to a public health center or hospital for further evaluation. At these medical institutions, blood samples were collected and forwarded to the Institute of Public Health and Environment, the designated confirmatory diagnostic institution (Figure 1).

Dengue Virus Laboratory Diagnosis

To confirm dengue virus infection, whole blood specimens from the 12 RDT-positive individuals were analyzed at the Institute of Public Health and Environment. Confirmatory testing included real-time reverse transcription polymerase chain reaction (RT-PCR) for NS1 antigen detection and IgM/IgG enzyme-linked immunosorbent assays (ELISAs) targeting envelope- and membrane-specific antibodies [9,10]. A case was considered confirmed if dengue virus-

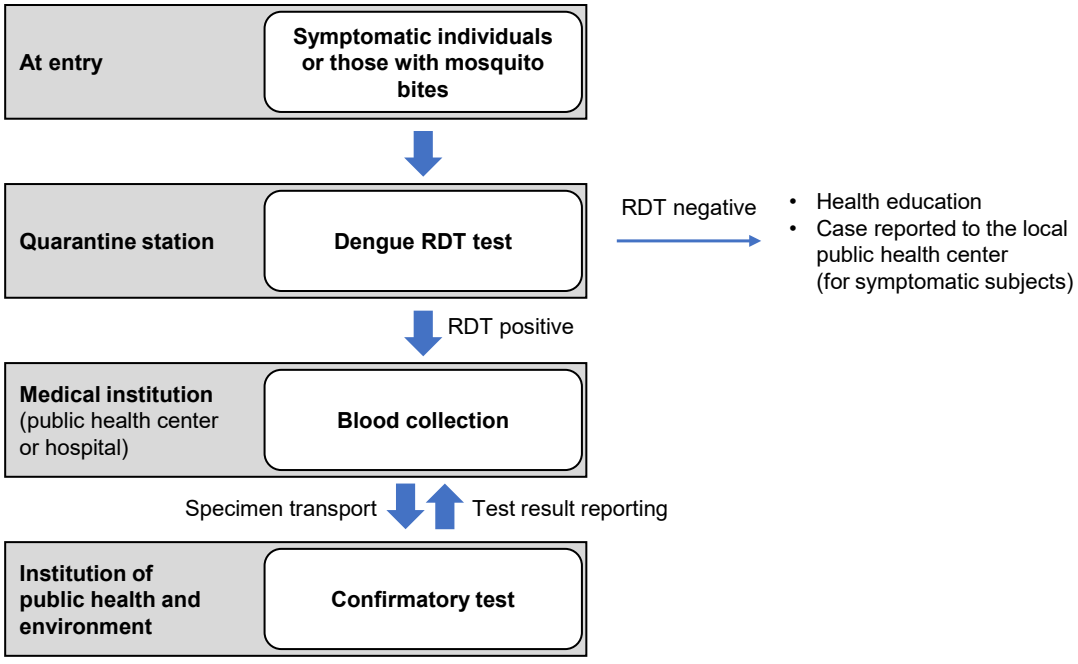


Figure 1. Dengue virus testing procedures for travelers. RDT, rapid diagnostic testing.

specific genetic material was detected by PCR, or if a fourfold or greater increase in antibody titers was observed in convalescent-phase serum compared with the acute-phase sample.

IRB Approval

This study protocol was approved by the Institutional Review Board of the KDCA. The Ethics Committee waived the requirement for individual informed consent (approval number: KDCA-2025-08-01-PE-01).

Results

Among the 334 travelers who underwent RDT for dengue, 12 tested positive, and 3 were confirmed positive through diagnostic testing. By sex, males accounted for 176 cases (52.7%), slightly outnumbering females (158 cases, 47.3%). The largest age group was individuals in their 20s and 30s, with 194 cases (58.1%). Vietnam was the most common country of departure, reported in 138 cases (41.3%). The most frequent travel duration was 5 days or less, observed in 162 cases (48.5%). A large majority of RDTs were conducted on Korean nationals (98.2%). No confirmed dengue cases were identified among foreign nationals, asymptomatic travelers, or those who traveled for 10 days or less.

To evaluate the relationship between RDT band intensity and confirmatory diagnostic outcomes, we analyzed the 12 RDT-positive cases. Excluding one case in which confirmatory testing was not performed, the remaining 11 were classified into 5 levels according to RDT intensity. All 7 cases with marginally positive RDT results were confirmed negative (0%) through diagnostic testing. In contrast, among the 4 cases with RDT intensity categorized as weakly positive or higher, 3 (75.0%) were confirmed positive.

Symptomatic travelers with positive RDT results were referred to medical institutions for confirmatory diagnostic testing in accordance with the "Traveler Dengue Virus Testing Procedure," where blood samples were collected (Figure 1). To evaluate the timeliness of confirmatory reporting, we compared the interval between sample collection and result notification by institution type and day of the week. Hospitals required an average of 4.00 days to report results, whereas public health centers required 2.71 days. Samples collected on weekdays had a shorter mean turnaround time (2.33 days) than those spanning weekends (5.00 days). Notably, hospital-based samples collected over weekends took an average of 5.33 days, while all 5 samples collected at public health centers on weekdays were reported by the following day.

All 3 dengue cases detected early at the point of entry involved travelers to Vietnam, Indonesia, or both, with more than 10 days elapsed between departure and RDT screening. Common symptoms included fever, chills, headache, and itching. Two patients reported mosquito bites, while one

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was uncertain (Table 1). In every confirmed case, the RDT showed an intensity of weakly positive or higher (Figure 2).

Discussion

In this study, we analyzed 334 cases of dengue RDT performed at the quarantine stage to detect imported cases early, including 12 RDT-positive cases. All confirmed dengue cases presented with typical symptoms such as fever and headache. Although some travelers requested testing following mosquito bites, the participation of asymptomatic individuals remained low due to the symptom-based screening approach, and no asymptomatic infections were identified (Table 2).

Three dengue cases were confirmed at the point of entry, and all had a travel history involving Indonesia and Vietnam. These 2 countries, along with the Philippines and Thailand, have consistently accounted for a large proportion of imported dengue cases in the Republic of Korea in recent years, underscoring the need for proactive testing among travelers returning from these regions [11]. All 3 confirmed patients reported dengue-related symptoms such as fever and headache. While testing was also available to individuals who reported mosquito bites, the symptom-based screening strategy resulted in limited participation from asymptomatic travelers, and no asymptomatic cases were detected (Table 2). Given that asymptomatic infections may account for up to 60% of dengue cases [12], efforts should be made to encourage testing even in the absence of symptoms. In particular, travelers from high-risk countries should be urged to undergo testing if they experienced mosquito bites, which could be facilitated by adding mosquito bite history as a required item on entry health declaration forms.

Notably, all 3 confirmed cases exhibited RDT band intensity at the level of moderately positive or higher (Table 3; Figure 2). Consistent with these findings, prior studies have demonstrated that stronger RDT intensity correlates with a higher probability of true positivity [7]. A similar trend has been reported for severe acute respiratory syndrome coronavirus 2 rapid testing, where higher viral loads are associated with increased positivity rates [13]. Conversely, all 7 cases with marginal RDT results tested negative on confirmatory testing (Table 3). These outcomes may represent false positives, but it is also possible that the dengue incubation period was incomplete, particularly as most of these travelers had spent 5 days or fewer overseas, while the average incubation period of dengue is 5 to 7 days [14]. Therefore, individuals with marginal results should be advised to undergo repeat testing if symptoms develop or worsen.

In the Republic of Korea, no cases of mosquito-borne dengue transmission have been reported to date, aside from a healthcare-associated needle-stick incident [15,16]. However, because *A. albopictus*, a known vector for dengue, is widely distributed across the country, rapid responses are essential when confirmed cases are identified. To facilitate this, individuals with positive RDT results are instructed by quarantine officers to visit a public health center or hospital for confirmatory blood testing (Figure 1). During the study period, however, one traveler with a strongly positive RDT result declined confirmatory testing, and the case was not pursued further (Table 3). To prevent such losses to follow-up and ensure timely diagnosis, inter-agency coordination should be strengthened, including the option of directly transferring RDT-positive travelers from quarantine stations to designated medical institutions.

Delays in confirmatory testing were also observed. On average, confirmatory results required 4.00 days at hospitals and 2.71 days at public health centers (Table 4). The longer delays at hospitals were largely attributable to scheduled specimen transport, whereas public health centers were able to send samples to public health laboratories immediately

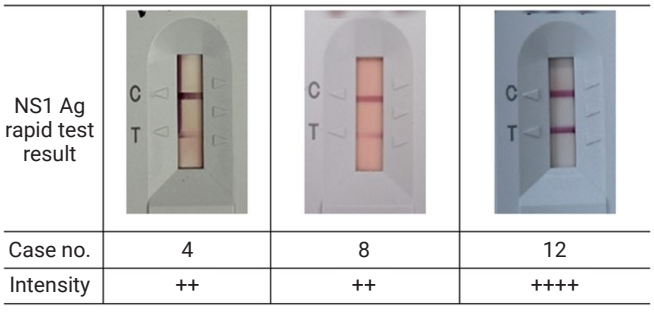


Figure 2. Rapid diagnostic testing results for confirmed dengue patients. C, control line; T, test line.

Table 1. Characteristics of confirmed dengue cases

Case no.	Travel country	Travel period (d)[a]	Mosquito bite	Symptom
4	Vietnam	11	Unknown	Fever, chills, headache, lethargy
8	Vietnam, Indonesia	13	O	Fever, chills, headache, itching
12	Indonesia	14	O	Fever, chills, headache, cough, nausea, itching

[a]Period from departure date in Korea to rapid diagnostic testing.

Table 2. Characteristics of RDT subjects at Gimhae International Airport (2022–2024)

Variable	Total RDT (*n* = 334)	RDT positive (*n* = 12)	Confirmatory test positive (*n* = 3)
Sex			
Male	176 (52.7)	8 (66.7)	2 (66.7)
Female	158 (47.3)	4 (33.3)	1 (33.3)
Age (y)			
< 20	49 (14.7)	2 (16.7)	0 (0)
20–39	194 (58.1)	5 (41.7)	1 (33.3)
40–59	78 (23.4)	4 (33.3)	2 (66.7)
≥ 60	13 (3.9)	1 (8.3)	0 (0)
Travel country			
Vietnam	138 (41.3)	6 (50.0)	2 (66.7)
Philippines	70 (21.0)	4 (33.3)	0 (0)
Thailand	69 (20.7)	2 (16.7)	0 (0)
Indonesia	26 (7.8)	1 (8.3)	1 (33.3)
Other	41 (12.3)	0 (0)	0 (0)
Travel period (d)			
≤ 5	162 (48.5)	1 (8.3)	0 (0)
6–10	122 (36.5)	6 (50.0)	0 (0)
≥ 11	48 (14.4)	5 (41.7)	3 (100.0)
Unknown	2 (0.6)	0 (0)	0 (0)
Symptoms			
Symptomatic	282 (84.4)	11 (91.7)	3 (100.0)
Asymptomatic	52 (15.6)	1 (8.3)	0 (0)
Nationality			
Domestic	328 (98.2)	12 (100.0)	3 (100.0)
Foreigner	6 (1.8)	0 (0)	0 (0)

Data are presented as *n* (%).
RDT, rapid diagnostic testing.

Table 3. Analysis of positive cases of RDT at Gimhae International Airport (2022–2024)

Case no.	Rapid test result[a]			Confirmatory test result	
	NS1	IgG	IgM	PCR	ELISA
1	+	–	–	–	–
2	+	–	–	–	–
3	-	–	++	–	–
4	++	–	–	Not performed	+
5	+	–	–	–	–
6	+	–	–	–	–
7	++	–	–	Not performed	Not performed
8	++	–	–	+	–
9	+	–	–	–	–
10	+	–	–	–	–
11	+	–	–	–	–
12	++++	–	–	+	Not performed

RDT, rapid diagnostic testing; Ig, immunoglobulin; PCR, polymerase chain reaction; ELISA, enzyme-linked immunosorbent assay.
[a]RDT results are shown as follows; ++++, strongly positive; +++, moderately positive; ++, weakly positive; +, marginally positive; –, negative.

upon collection. Turnaround times were shorter for weekday arrivals (2.33 days) than for weekend arrivals (5.00 days), suggesting that reduced weekend operations contributed to delays. To address this, quarantine stations and public health centers may need to expand their capacity for blood sampling and confirmatory testing on weekends. Furthermore,

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Table 4. Comparison of test duration according to day of the week and medical institution

Variable	No. of cases (n = 11)[a]	Test duration (d)[b]	
		Average	Standard error
Medical institution			
Hospital	7	4.00	0.41
Public health center	4	2.71	0.47
Day of the week[c]			
Weekdays	6	2.33	0.33
Weekends[d]	5	5.00	0.84
Combination			
Hospital+weekends	3	5.33	1.45
Public health center+weekdays	5	2.00	0
Others	3	4.33	0.33

[a]Of the total 12 rapid diagnostic testing-positive cases, 1 case did not have a confirmatory diagnostic test performed. [b]Time taken from blood collection to diagnostic test results. [c]Refers to the day of the week on which blood was drawn. [d]Weekends include Fridays, Saturdays and Sundays.

travelers with positive RDT results should be advised to limit social activities until results are confirmed. Another approach to reduce delays would be to incorporate NS1 antigen detection by RDT into the confirmatory diagnostic criteria. Although current KDCA guidelines do not accept RDT results as confirmatory for dengue, the World Health Organization already recognizes NS1 antigen detection by RDT, along with ELISA, as acceptable diagnostic confirmation [17]. If adopted, this policy would allow quarantine officers to issue a certificate of positivity at the point of entry—even on weekends—without requiring additional sample collection at medical institutions, thereby expediting treatment initiation. However, clear diagnostic criteria must be established to address the relatively high false-positive rate associated with RDT.

This study examined the characteristics and response processes of dengue cases detected early at a major port of entry. Nonetheless, the small sample size and retrospective design limited the scope of statistical analysis, and detailed information such as serotype identification was not available. Future studies with larger datasets are needed to improve the reliability and generalizability of these findings.

Conclusion

This study analyzed dengue cases identified early at Gimhae International Airport from 2022 to 2024, with a focus on the implementation of RDT and subsequent confirmatory testing. Based on these findings, practical measures were proposed to improve diagnostic timeliness and strengthen the response system. These results provide foundational evidence to improve early detection and rapid response strategies for dengue at quarantine sites.

Notes

Ethics Approval

This study was approved by the Institutional Review Board of the KDCA (approval number: KDCA-2025-08-01-PE-01).

Conflicts of Interest

The authors have no conflicts of interest to declare.

Funding

None.

Availability of Data

All data generated or analyzed during this study are included in this published article. For other data, these may be requested through the corresponding author.

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- Gene nomenclature: Current standard international nomenclature for genes should be adhered to. Genes should be typed in italic font and include the accession number. For human genes, use the genetic notation and symbols approved by the HUGO Gene Nomenclature Committee (http://www.genenames.org/) or refer to PubMed (http://www.ncbi.nlm.nih.gov/sites/entrez).
- Units: Système International (SI) units must be used, with the exception of blood pressure values, which are to be reported in mmHg. Please use the metric system for expressions of length, area, mass, and volume. There should be a space between the numerals and the unit symbol. When indicating time, the 24-hour system is to be used.
- Math formulae: Present simple formulae in the line of normal text where possible and use the solidus (/) instead of a horizontal line for small fractional terms, e.g., X/Y. In principle, variables are to be presented in italics. Powers of e are often more conveniently denoted by "exp." Number consecutively any equations that have to be displayed separately from the text (if referred to explicitly in the text).

Reporting Guidelines for Specific Study Designs

For specific study designs, such as randomized control studies, studies of diagnostic accuracy, meta-analyses, observational studies, and non-randomized studies, authors should adhere the reporting guidelines relevant to their specific research design and submit a checklist. A good source of reporting guidelines is the EQUATOR Network (https://www.equator-network.org/) and NLM (https://www.nlm.nih.gov/services/research_report_guide.html).

Manuscript Types

PHPR publishes editorials, original articles, review articles, guidelines, data profiles (including cohort profiles), special articles, short communications, viewpoints, editorials, commentaries, and correspondence, and book reviews, and perspectives.

- **Original articles** are papers containing results of basic and clinical investigations, which are sufficiently well documented to be acceptable to critical readers. These articles should be written in the following format: title page; abstract and keywords; main body (introduction, materials and methods, results, discussion, conclusion [if any]); references; and tables and figure legends. Manuscript limitations are 5,000 words, excluding the abstract, references, and tables and figure legends.

- **Review articles** provide concise reviews of subjects important to medical researchers, and can be written by an invited medical expert. These have the same format as original articles, but the details may be more flexible depending on the content. Manuscript limitations are 6,500 words from introduction to conclusion, 100 references, 10 figures and 10 tables. The abstract should not exceed 200 words, and must be written as one unstructured paragraph.
- **Systematic reviews** should adhere to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The template for systematic reviews can be downloaded from https://ophrp.org/file/PHRP_Systematic%20Review_PRISMA.docx.
- **Guidelines** are similar to original articles, but provide evidence-based recommendations expected to impact clinical research and practice. This category can include consensus-based statements of reporting standards or clinical practice guidelines.
- **Data Profiles (including Cohort Profiles)** present large data sets from specific populations that could be analyzed in epidemiological studies. Data Profiles should be structured with the following headings in the main text: Introduction, Collection, Data Resource Use, Strengths and Weaknesses, and Access. Cohort Profiles present up-to-date information about large population-based cohorts for which long-term data collection is planned. Data Profiles should be structured with the following headings in the main text: Introduction, Study Participants, Measurements, Key Findings, Strengths and Weaknesses, and Access. The main text of Data and Cohort Profiles is limited to 4,000 words, with an unstructured abstract of up to 200 words, a maximum of 7 tables and figures, and no more than 40 references.
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- **Brief reports** deal with issues of importance to biomedical researchers and follow the general guidelines for original articles. The manuscript should not exceed 2,000 words, excluding references, tables and figures, and must include a structured abstract of no more than 250 words.
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3 tables and figures combined is allowed. Authorship is generally limited to 1–2, and these articles are often commissioned by the Editorial Board.

Key features and limits of articles are summarized in Table 1 below.

Table 1. Key features and limits of articles

Type of article	Abstract (words)	Text (words)*	References	Tables and figures
Original article	Structured, 250	5,000	-	-
Review article	200	6,500	100	10 Tables 10 Figures
Data profile	200	4,000	40	7
Special article	200	3,500	40	7
Brief report	Structured, 250	2,000	-	-
Short communication	Structured, 250	3,000	-	-
Viewpoint	150	3,000	30	4
Editorial	Not required	1,000	20	-
Commentary	Not required	500	10	2
Correspondence	Not required	500	-	2
Perspective	Not required	1,500	20	3

*Excluding abstract, references, tables, and figure legends.

Title Page

Title page should include (1) the title of the article (less than 50 words); (2) name of the authors (first name, middle initial, last name in capitals) and institutional affiliation including the name of department(s) and institution(s) of each author; (3) name, full address (including the postal code) of the institutional affiliation, telephone and e-mail address of the corresponding author; (4) a running title of 50 characters or less including blank spaces; and (5) notes (disclaimers). Notes include ethics approval and consent to participate, conflict of interest, funding, availability of data, authors' contributions according to the CRediT taxonomy (https://credit.niso.org/), additional contributions, and ORCID of all authors. All contributors who do not meet the criteria for authorship as defined above should be listed in an additional contribution section. Examples of those who might be acknowledged include a person who provided purely technical help, writing assistance, or a department chair who provided only general support. Authors should disclose whether they had any writing assistance and identify the entity that paid for this assistance.

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An abstract and 3–6 relevant keywords (in alphabetical order) are required. Abstracts should be no more than 250 words in length. Abstracts should be structured, with the following section headings: Objectives, Methods, Results, Conclusion. For selecting keywords, refer to the MeSH browser (http://www.ncbi.nlm.nih.gov/mesh).

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- **Introduction** should provide concise yet sufficient background information about the study to provide the readers with a better understanding of the study, avoiding a detailed literature survey or a summary of the results.
- **Materials and methods** should contain detailed procedures of the study or experiment including investigation period, methods of subject selection, and information on subjects such as age, sex or gender, and other significant features, in order to enable the experiment to be repeated. A procedure that has been already published or standardized should be described only briefly using literature citations. Clinical trials or experiments involving laboratory animals or pathogens must elaborate on the animal care and use and experimental protocols, in addition to mentioning approval from the relevant committees. The sources of special equipment and chemicals must be stated with the name of the manufacturer. All statistical procedures used in the study and criteria for determining significance levels must be described. Ensure correct use of the terms "sex" (when reporting biological factors) and "gender" (identity, psychosocial or cultural factors). Unless inappropriate, report the sex and/or gender of study participants, the sex of animals or cells, and describe the methods used to determine sex or gender. If the study involved an exclusive population (only one sex, for example), authors should justify why, except in obvious cases (e.g., prostate cancer). Authors should define how they determined race or ethnicity, and justify its relevance. Institutional Review Board approval and informed consent procedures can be described as follows: The study protocol was approved by the Institutional Review Board of OOO (IRB No: OO-OO-OO). Informed consent was obtained by all participants (or the participant's legal guardian) / Informed consent was waived by the IRB.
- **Results** should be presented in logical sequence. Only the most important observations should be emphasized or summarized, and the main or the most important

findings should be mentioned first. Tables and figures must be numbered in the order they are cited in the text, kept to a minimum, and should not be repeated. Supplementary materials and other details can be separately presented in an appendix. The authors should state the statistical method used to analyze the results (statistical significance of differences) with the probability values given in parentheses.

- **Discussion** should contain an interpretation and explanation of the results and important aspects of the study, followed by the conclusions drawn from them. Information already mentioned in the Introduction or Results sections should not be repeated and the main conclusions of the study may be presented in the discussion.
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References

Authors are responsible for the accuracy and completeness of their references and for correct text citations.

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- **Journal articles**
  1. Park AK, Kim IH, Kim J, et al. Genomic surveillance of SARS-CoV-2: distribution of clades in the Republic of Korea in 2020. Osong Public Health Res Perspect 2021; 12:37-43.
  2. Hyun J, Lee JH, Park Y, et al. Interim epidemiological and clinical characteristic of COVID-19 28 cases in South Korea. Public Health Wkly Rep 2020;13:464-74. Korean.
  3. Gultekin V, Allmer J. Novel perspectives for SARS-CoV-2 genome browsing. J Integr Bioinform 2021 Mar 15 [Epub]. https://doi.org/10.1515/jib-2021-0001.
- **Books**
  1. Riffenburgh RH, Gillen DL. Statistics in medicine. 4th ed. Academic Press; 2020.
  2. Miller DD. Minerals. In: Damodaran S, Parkin KL, editors. Fennema's food chemistry. 5th ed. CRC Press; 2017. p. 627-80.
  3. Ministry of Employment and Labor (KR). Statistics on occupational injuries and illnesses, 2008. Ministry of Employment and Labor; 2009. Korean.
- **Websites**
  1. World Health Organization (WHO) (CH). COVID-19 vaccines [Internet]. WHO; 2021 [cited 2021 Mar 15]. Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/covid-19-vaccines.
- **Conference papers**
  1. Christensen S, Oppacher F. An analysis of Koza's computational effort statistic for genetic programming. In: EuroGP 2002: Proceedings of the 5th European Conference on Genetic Programming; 2002 Apr 3-5; Kinsdale, IE. Springer; 2002. p. 182-91.
- **Dissertation**
  1. Park HY. The role of the thrombomodulin gene in the development of myocardial infarction [dissertation]. Yonsei University; 2000.

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Tables should be simple, self-explanatory, and supplemental, and should not duplicate the text or figures. Each table must be on a separate page, not exceeding 1 page when printed, and have a concise and informative title. The tables should be numbered with Arabic numerals in consecutive order.

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If any materials are not enough to be included in the main text such as questionnaires, they can be listed in the Appendix. Any supplementary materials that help the understanding of readers or contain too great an amount of data to be included in the main text may be placed as supplementary data. Not only a recording of the abstract, text, audio or video files, but also data files should be added here.

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