



The impact of body mass index on mortality according to age in hemodialysis patients: an analysis of the Korean Renal Data System

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The impact of age on the relationship between body mass index (BMI) and all-cause mortality in hemodialysis (HD) patients is not clearly understood. Using data from the Korean Renal Data System (2001–2022), we analyzed 66,129 HD patients, stratified into young (<65 years, n = 24,589), younger-old (65–74 years, n = 17,732), and older-old (≥75 years, n = 23,808) groups. Patients were categorized into BMI quartiles, and survival outcomes were evaluated using Kaplan-Meier curves and event time ratios for the relative change in the survival time. During the follow-up period, 14,360 of the patients (21.7%) died, with a median follow-up of 3.4 years. Kaplan-Meier curves revealed poorer outcomes in lower BMI quartiles across all age groups. The lowest BMI quartile was significantly associated with a shorter survival time compared to the highest BMI quartile, with a 15% reduction in the young group (p = 0.001) and a 12% reduction in the older-old group (p = 0.002). Predicted survival time increases with rising BMI in the young group, but the rate of increase slows in the younger-old group and plateaus in the older-old group after a BMI of 25 kg/m². Lower BMI correlates with higher mortality, particularly in younger HD patients.

Keywords: Aged, Body mass index, Mortality, Renal dialysis, Survival

Introduction

In the general population, obesity is related to higher all-cause mortality and cardiovascular mortality [1,2] and raises the risk of chronic kidney disease and end-stage kidney disease (ESKD) [3–5]. However, obesity has been associated with better survival in patients with ESKD, a phenomenon known as the ‘obesity paradox’ [6–8]. This paradoxical relationship has also been observed in patients with congestive heart failure, chronic obstructive pulmonary disease, and among geriatric populations [9–11]. Sev-

eral hypotheses have been proposed to explain this reverse epidemiology of obesity, including reverse causation, more stable hemodynamic status, interactions between endotoxins and lipoproteins, and the malnutrition-inflammation complex syndrome [8].

While obese patients with ESKD tend to exhibit lower mortality rates, the impact of age on this relationship is not clearly understood. For example, one study based on a large cohort of hemodialysis (HD) patients in the United States showed that higher body mass index (BMI) was consistently linked with better survival, regardless of the patient's age,

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with this association being more pronounced in individuals younger than 65 years [12]. Furthermore, an analysis utilizing data from the nationwide Korean ESKD registry revealed that underweight patients undergoing HD exhibited higher mortality rates across all age groups (<40 years, 40–59 years, and ≥60 years), whereas the beneficial effect of overweight status was only evident in the middle age group (40–59 years) [13]. Conversely, Hoogeveen et al. [14] found that among incident dialysis patients followed up for 7 years, obesity was associated with a nearly two-fold increase in mortality among those younger than 65 years, but no such correlation was observed among older dialysis patients.

Previous studies often categorized patients aged ≥65 years as a single group, but with the increasing number of very elderly dialysis patients aged ≥75 years, a more detailed analysis is necessary [15–17]. Research shows that patients aged ≥75 years have a higher mortality than those aged 65 to 74 years, due to increased comorbidities, malnutrition, and frailty [18–21]. While mortality rates have shown a decreasing trend for patients undergoing HD in both age groups in Europe and the United States [15,22], a recent Korean study reports a continued rise in mortality for those aged ≥75 years, despite a decline for patients aged 65 to 74 [23]. Furthermore, the study found that BMI is lower in the ≥75-year group compared to the 65- to 74-year group. Therefore, this study aims to examine the impact of BMI on mortality, stratified by age, with elderly patients further subdivided into the 65–74 and ≥75-year age groups.

Methods

Study population

We conducted a retrospective analysis of data from patients undergoing HD using the Korean Renal Data System (KORDS), a comprehensive national registry of Korean patients with ESKD that is updated annually [24]. A total of 173,216 patients seen from 2001 to 2023 were included in the initial dataset. All patients were prevalent HD patients who had been undergoing dialysis for more than 3 months. The following exclusion criteria were applied: 1) missing data or errors, including no dialysis start date, death date, or BMI; or cases with enrollment dates preceding the dialysis start date for survivors; 2) patients with a dialysis start date in 2000 or earlier; and 3) patients under the age of

18 years. After applying these exclusion criteria, a total of 66,129 patients were included in this study. Patients were divided into three groups: a “young” group (<65 years, $n = 24,589$, 37.2%), a “younger-old” group (65–74 years, $n = 17,732$, 26.8%), and an “older-old” group (≥75 years, $n = 23,808$, 36.0%). A flow diagram of patient selection is provided in [Supplementary Fig. 1](#) (available online). Additionally, the 66,129 patients were divided into BMI quartiles: BMI <19.7 kg/m² ($n = 16,493$), 19.7–21.8 kg/m² ($n = 16,558$), 21.8–24.2 kg/m² ($n = 16,483$), and ≥24.2 kg/m² ($n = 16,595$).

Clinical parameters and definitions of cause of death

The initial characteristics of the study participants were recorded at the start of HD. BMI was calculated by dividing body weight in kilograms by the square of height in meters. Body weight data represented dry weight, measured after dialysis. Definitions of the causes of death aligned with those in the KORDS data. Cardiac diseases as causes of death included coronary artery disease, heart failure, pericardial effusion, and arrhythmia. Vascular diseases encompassed cerebrovascular accidents, pulmonary embolism, gastrointestinal bleeding, gastrointestinal embolism, and other vascular conditions. The International Classification of Diseases, 10th revision codes for the causes of death are summarized in [Supplementary Table 1](#) (available online).

Statistical analyses

Categorical variables are presented as absolute values and percentages, while continuous variables are expressed as means ± standard deviations. The chi-square tests were utilized to compare categorical variables between groups, while analysis of variance was employed to compare continuous variables between groups. Kaplan-Meier analysis was used to compare survival between BMI groups stratified by age groups, with the log-rank test used to compare the survival distributions across groups.

For survival time analysis, we used the Cox proportional hazards model when the proportional hazards assumption was met. However, when this assumption was violated, we applied the accelerated failure time (AFT) model with a Weibull distribution. Coefficients from the AFT model were exponentiated to yield event time ratios (ETRs), where an ETR >1 indicated prolonged survival and an ETR <1 sug-

gested shortened survival compared to the reference group [25]. The highest BMI quartile ($\text{BMI} \geq 24.2 \text{ kg/m}^2$) was set as the reference in both the AFT and Cox models to specifically emphasize the impact of lower BMI on survival, as lower BMI has been consistently associated with higher mortality in dialysis patients [26]. Both AFT and Cox models followed the same adjustment scheme across three models: a crude model, a model adjusted for age, sex, and primary renal disease, and a model further adjusted for laboratory values that included hemoglobin, albumin, and phosphorus. A restricted cubic spline analysis was conducted using the AFT model, adjusted for age and sex, to explore the relationship between BMI and survival time across age groups. Knots were chosen based on the quartile of BMI.

All statistical analyses were performed using R software (ver. 4.2.1; R Foundation for Statistical Computing), with significance set at $p < 0.05$ for all analyses.

Results

Baseline characteristics

Table 1 shows the baseline characteristics of participants categorized into BMI quartiles. Mean age was 68.5 years, with a higher proportion of males (60.9%) than females (39.1%) ($p < 0.001$). The most prevalent primary renal disease was diabetes mellitus (DM, 49.3%), followed by hypertension (HTN, 20.0%), and glomerulonephritis (GN, 8.9%) ($p < 0.001$). The mean BMI was 22.2 kg/m^2 . The leading cause of mortality was cardiac-related (7.0%), followed by infection (4.6%), and vascular causes (2.5%) ($p < 0.001$).

Analyses based on BMI quartiles revealed the mean age decreased with increasing BMI quartile, from 69.6 years in the lowest quartile to 66.1 years in the highest quartile ($p < 0.001$). Notably, males constituted the smallest proportion

Table 1. Baseline characteristics of patients according to BMI

Characteristic	Total	BMI (kg/m^2)				p-value ^a
		<19.7	19.7–21.8	21.8–24.2	≥ 24.2	
No. of patients	66,129	16,493	16,558	16,483	16,595	
Age (yr)	68.5 ± 13.7	69.6 ± 14.8	69.2 ± 13.3	69.0 ± 12.8	66.1 ± 13.5	<0.001
Male sex	40,251 (60.9)	8,563 (51.9)	10,375 (62.7)	10,885 (66.0)	10,428 (62.8)	<0.001
BMI (kg/m^2)	22.2 ± 5.5	17.9 ± 2.3	20.8 ± 0.6	22.9 ± 0.7	27.1 ± 8.4	<0.001
Primary renal disease						<0.001
Diabetes mellitus	32,572 (49.3)	6,781 (41.1)	7,925 (47.9)	8,421 (51.1)	9,445 (56.9)	
Hypertension	13,197 (20.0)	3,579 (21.7)	3,312 (20.0)	3,320 (20.1)	2,986 (18.0)	
Glomerulonephritis	5,894 (8.9)	1,741 (10.6)	1,587 (9.6)	1,384 (8.4)	1,182 (7.1)	
Others	5,710 (8.6)	1,782 (10.8)	1,469 (8.9)	1,287 (7.8)	1,172 (7.1)	
Unknown	8,756 (13.2)	2,610 (15.8)	2,265 (13.7)	2,071 (12.6)	1,810 (10.9)	
Cause of death						
Cardiac	4,646 (31.9)	1,382 (29.4)	1,205 (31.0)	1,094 (32.2)	965 (37.2)	<0.001
Infection	1,709 (20.9)	519 (23.6)	492 (19.6)	420 (20.1)	278 (19.0)	<0.001
Vascular	3,051 (11.7)	1,112 (11.0)	761 (12.7)	684 (12.4)	494 (10.7)	<0.001
Cancer	878 (6.0)	263 (5.6)	239 (6.2)	236 (6.9)	140 (5.4)	<0.001
Liver	285 (2.0)	74 (1.6)	87 (2.2)	76 (2.2)	48 (1.8)	0.009
Social	336 (2.3)	117 (2.5)	112 (2.9)	67 (2.0)	40 (1.5)	<0.001
Miscellaneous	3,679 (25.2)	1,241 (26.4)	986 (25.4)	822 (24.2)	630 (24.3)	<0.001
No. of total death	14,584	4,708	3,882	3,399	2,595	
Laboratory findings						
Hemoglobin (g/dL)	10.5 ± 12.1	10.4 ± 15.5	10.4 ± 12.6	10.5 ± 10.8	10.5 ± 8.0	0.85
Albumin (g/dL)	3.9 ± 0.5	3.7 ± 0.6	3.8 ± 0.5	3.9 ± 0.5	3.9 ± 0.5	<0.001
Phosphorus (mg/dL)	4.8 ± 1.6	4.5 ± 1.7	4.7 ± 1.6	4.8 ± 1.6	5.1 ± 1.6	<0.001

The initial characteristics of the study participants were recorded at the start of hemodialysis.

Data are expressed as number only, mean $\pm$ standard deviation, or number (%).

BMI, body mass index.

^aContinuous variables were compared using t test, and categorical variables were compared by using chi-square test.

(51.9%) of the lowest BMI quartile, while females accounted for the highest proportion (48.1%) compared to the other quartiles.

As BMI increased, the proportion of patients with DM as the primary renal disease increased from 41.1% in the lowest BMI quartile to 56.9% in the highest ($p < 0.001$). Conversely, the proportion of HTN and GN as primary renal diseases decreased from 21.7% and 10.6% in the lowest BMI quartile to 18.0% and 7.1% in the highest, respectively ($p < 0.001$ for each variable). These findings indicate that higher BMI quartiles were associated with a greater prevalence of DM and a lower prevalence of HTN and GN as primary renal diseases.

In laboratory findings, hemoglobin levels remained consistent across all BMI quartiles, with no significant differences ($p = 0.85$). However, both albumin and phosphorus levels increased progressively with BMI, with albumin ranging from 3.74 g/dL in the lowest quartile to 3.93 g/dL in the highest quartile, and phosphorus ranging from 4.50 to 5.07 mg/dL, respectively ($p < 0.001$ for both).

Analyses of the causes of death across BMI categories revealed that the proportion of deaths due to cardiac disease increased progressively with BMI, from 29.4% in the lowest BMI quartile to 37.2% in the highest BMI quartile ($p < 0.001$). Conversely, infection-related deaths were highest in the lowest BMI quartile (23.6%) and decreased to 19.0% in the highest BMI quartile ($p < 0.001$ for both).

Survival curves based on body mass index quartiles across age groups

Over the entire follow-up period, 14,360 of the 66,129 patients (21.7%) died. The median follow-up time was 3.4 years. Kaplan-Meier curves based on BMI quartiles across age groups are shown in Fig. 1. In all age groups, significantly lower survival rates were observed in the lowest BMI quartile, while subjects in higher BMI quartiles had better survival rates ($p < 0.001$ for each age group).

Association between body mass index and survival time across age groups

In this analysis, since the Cox proportional hazards assumption was violated, the AFT model with a Weibull distribution was used to examine the association between BMI and survival time using the highest BMI quartile as the reference. After multivariable adjustment in Model 3, the lowest BMI quartile was significantly associated with a shorter survival time compared to the highest BMI quartile, with a 15% reduction in the young group (ETR, 0.85; 95% confidence interval [CI], 0.78–0.94; $p = 0.001$) and a 12% reduction in the older-old group (ETR, 0.89; 95% CI, 0.82–0.96; $p = 0.002$) (Table 2). However, in the younger-old group, no significant difference in survival time was observed for the lowest BMI quartile (ETR, 0.96; 95% CI,

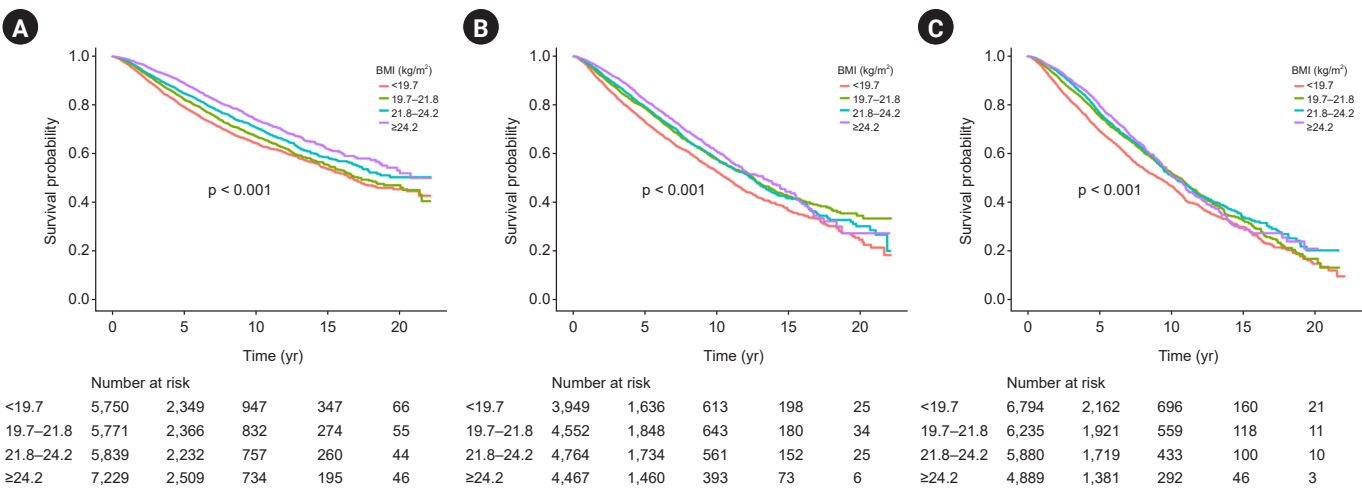


Figure 1. Kaplan-Meier curves according to BMI quartiles across age groups. (A) Survival curves in patients aged <65 years. (B) Survival curves in patients aged 65 to 74 years. (C) Survival curves in patients aged ≥75 years. BMI, body mass index.

0.88–1.06; $p = 0.45$).

Sex- and age-specific comparisons of body mass index and survival time

The AFT model examined the relationship between BMI and survival time, stratified by sex and age. Among males, the lowest BMI quartile was significantly associated with a 12.5% shorter survival compared to the highest BMI quartile (ETR, 0.88; 95% CI, 0.82–0.94; $p < 0.001$), and the second BMI quartile showed a marginal association, with a 6.4% shorter survival (ETR, 0.94; 95% CI, 0.88–1.00; $p = 0.05$) (Table 3). In females, no significant association was observed for the lowest BMI quartile (ETR, 0.93; 95% CI,

0.86–1.01; $p = 0.07$).

In age-stratified analysis using the young group as the reference, survival time decreased with age (Table 4). The younger-old group had 28.1% shorter survival compared to the young group (ETR, 0.72; 95% CI, 0.70–0.74; $p < 0.001$), and the older-old group showed a 37.8% shorter survival (ETR, 0.62; 95% CI, 0.60–0.64; $p < 0.001$).

Body mass index and predicted survival time by age group

In the analysis of BMI and predicted survival time across age groups using the AFT model and represented by restricted cubic spline curves, the young group demonstrated a continuous increase in survival time with rising BMI,

Table 2. Association between BMI and survival time across age groups

Age (yr)	BMI (kg/m ²)	Model 1		Model 2		Model 3	
		ETR (95% CI)	p-value	ETR (95% CI)	p-value	ETR (95% CI)	p-value
<65	<19.7	0.67 (0.62–0.72)	<0.001	0.59 (0.55–0.64)	<0.001	0.85 (0.78–0.94)	0.001
	19.7–21.8	0.73 (0.68–0.79)	<0.001	0.69 (0.64–0.74)	<0.001	0.92 (0.83–1.01)	0.09
	21.8–24.2	0.82 (0.76–0.89)	<0.001	0.80 (0.74–0.87)	<0.001	0.96 (0.87–1.05)	0.36
	≥24.2			Reference			
65–74	<19.7	0.75 (0.70–0.81)	<0.001	0.70 (0.66–0.76)	<0.001	0.96 (0.88–1.06)	0.46
	19.7–21.8	0.88 (0.82–0.95)	<0.001	0.84 (0.78–0.91)	<0.001	1.03 (0.94–1.13)	0.54
	21.8–24.2	0.89 (0.83–0.96)	0.001	0.86 (0.80–0.93)	<0.001	0.98 (0.89–1.08)	0.70
	≥24.2			Reference			
≥75	<19.7	0.78 (0.74–0.83)	<0.001	0.76 (0.72–0.81)	<0.001	0.89 (0.82–0.96)	0.001
	19.7–21.8	0.91 (0.86–0.97)	0.002	0.91 (0.85–0.96)	0.001	0.99 (0.91–1.07)	0.69
	21.8–24.2	0.96 (0.90–1.03)	0.207	0.96 (0.90–1.02)	0.181	1.02 (0.93–1.10)	0.76
	≥24.2			Reference			

All tests were performed by using the baseline quartile of BMI ≥24.2 kg/m² as a reference group.

Model 1, crude. Model 2, adjusted for age, sex, and primary renal disease. Model 3, Model 2 + hemoglobin, albumin, and phosphorus.

BMI, body mass index; CI, confidence interval; ETR, event time ratio.

Table 3. Sex-specific analysis of BMI and survival time

Age (yr)	BMI (kg/m ²)	Model 1		Model 2		Model 3	
		ETR (95% CI)	p-value	ETR (95% CI)	p-value	ETR (95% CI)	p-value
Male	<19.7	0.61 (0.57–0.64)	<0.001	0.63 (0.60–0.66)	<0.001	0.88 (0.82–0.94)	<0.001
	19.7–21.8	0.72 (0.69–0.76)	<0.001	0.75 (0.71–0.78)	<0.001	0.94 (0.88–1.00)	0.05
	21.8–24.2	0.80 (0.76–0.84)	<0.001	0.82 (0.78–0.86)	<0.001	0.94 (0.88–1.01)	0.07
	≥24.2			Reference			
Female	<19.7	0.85 (0.80–0.90)	<0.001	0.78 (0.73–0.82)	<0.001	0.93 (0.86–1.01)	0.07
	19.7–21.8	0.98 (0.92–1.05)	0.61	0.94 (0.88–1.00)	0.04	1.07 (0.99–1.17)	0.10
	21.8–24.2	0.99 (0.93–1.06)	0.82	0.98 (0.92–1.04)	0.52	1.09 (1.00–1.18)	0.06
	≥24.2			Reference			

All tests were performed by using the baseline quartile of BMI ≥24.2 kg/m² as a reference group.

Model 1, crude. Model 2, adjusted for age, sex, and primary renal disease. Model 3, Model 2 + hemoglobin, albumin, and phosphorus.

BMI, body mass index; CI, confidence interval; ETR, event time ratio.

without any plateau (Fig. 2A). For the younger-old group, while survival time increased with BMI, but the slope of the increase slows around a BMI of 25 kg/m² (Fig. 2B). In the older-old group, the survival benefit of higher BMI diminished significantly after a BMI of around 25 kg/m², with no further substantial gains in survival time beyond this threshold (Fig. 2C).

Age and predicted survival time across body mass index quartiles in overall, 2-year, 7-year survival

Using a restricted cubic spline curve within the AFT model, with the highest BMI quartile as the reference (Fig. 3), we identified three key trends. First, predicted survival time consistently increased as age decreased across all BMI quartiles, confirming that younger patients generally experience better survival outcomes (Table 4). Second, 2-year survival was shorter than those for the 7-year survival

Table 4. Age-specific analysis of survival time

Age (yr)	Model 1	
	ETR (95% CI)	p-value
<65	Reference	
65–74	0.72 (0.70–0.74)	<0.001
≥75	0.62 (0.60–0.64)	<0.001

All tests were performed by using patients aged <65 years as a reference group.
Model 1, crude.
CI, confidence interval; ETR, event time ratio.

across all BMI quartiles and survival time increased with higher BMI in both 2-year and 7-year survival (Fig. 3D–I). Third, the decline in survival time with age was more pronounced in the 7-year analysis compared to the 2-year survival analysis (Fig. 3D, G).

Impact of dialysis vintage on survival time across body mass index quartiles

Given that the study population consists of prevalent HD patients, dialysis vintage could potentially affect mortality outcomes. Therefore, we categorized dialysis vintage into three groups: vintage 1 (<1 year), vintage 2 (1–2 years), and vintage 3 (2–5 years). We performed a Cox proportional hazards analysis to evaluate the mortality risk across BMI quartiles (Supplementary Table 2, available online). The lowest BMI was consistently associated with a higher mortality risk in patients across the three vintage groups, particularly among the young and the older-old groups. In vintage 3, both the lowest BMI quartile and the second BMI quartile were significantly associated with higher mortality across all age groups, including the younger-old group.

Discussion

In this study, we evaluated the relationship between BMI and mortality stratified by age among patients undergoing HD using KORDS data. Our analysis revealed several

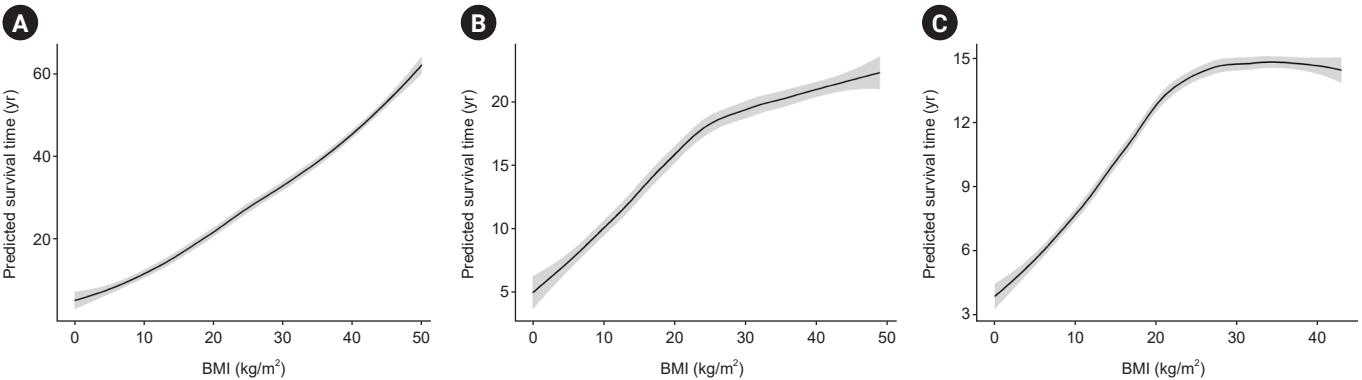


Figure 2. BMI and predicted survival time across age groups. (A) BMI and predicted survival time in patients aged <65 years. (B) BMI and predicted survival time in patients aged 65 to 74 years. (C) BMI and predicted survival time in patients aged ≥75 years. Predicted survival time based on BMI was modeled using a restricted cubic spline in an accelerated failure time model, adjusted for age and sex. Thick lines depict continuously adjusted predicted survival times, and the grey area reflects 95% confidence intervals for the estimates.
BMI, body mass index.

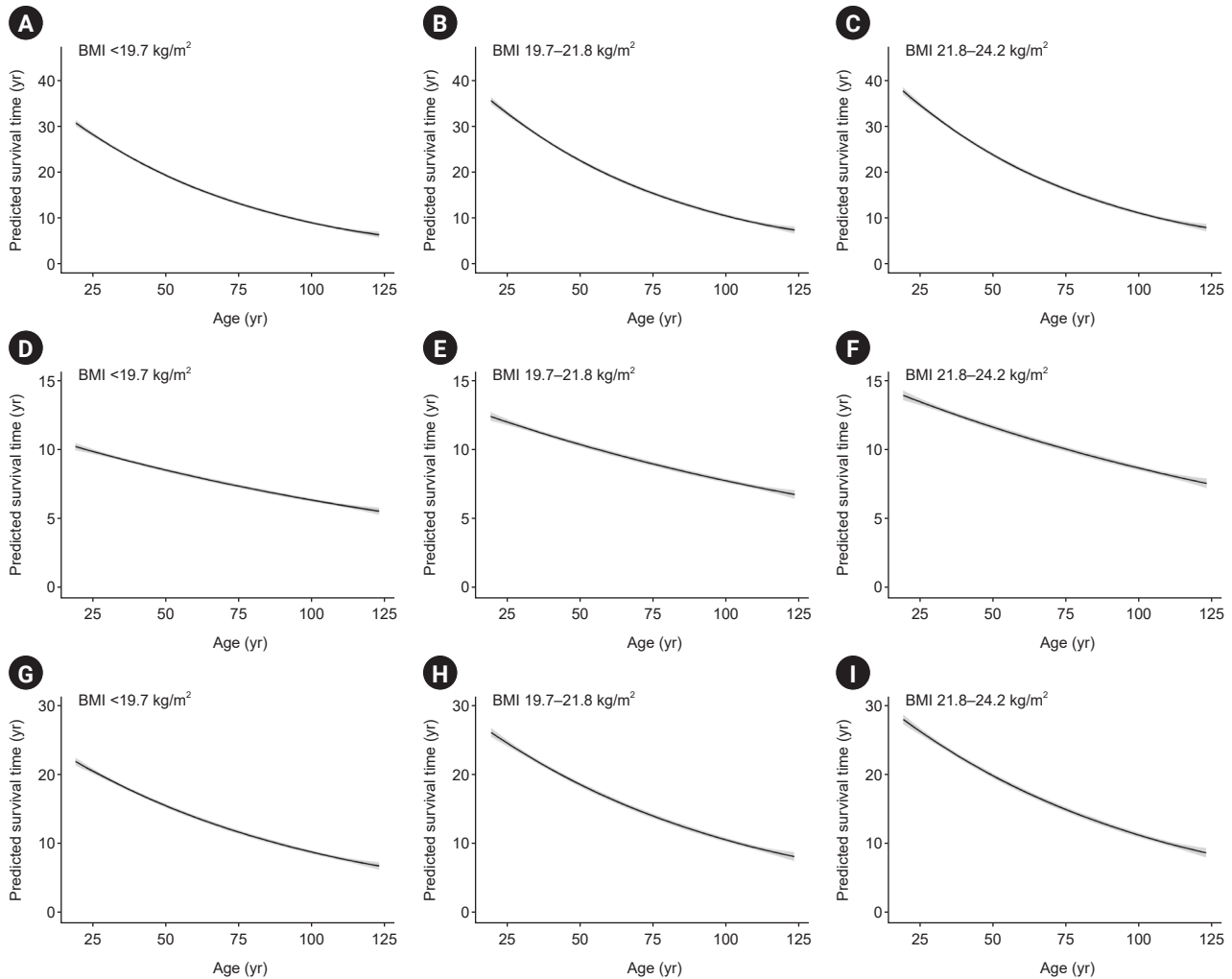


Figure 3. Age and predicted survival time across BMI quartiles for overall, 2-year, and 7-year survival. (A–C) Age and predicted survival time for overall survival by BMI quartile: (A) BMI <19.7 kg/m², (B) BMI 19.7–21.8 kg/m², and (C) BMI 21.8–24.2 kg/m². (D–F) Age and predicted survival time in 2-year survival by BMI quartiles: (D) BMI <19.7 kg/m², (E) BMI 19.7–21.8 kg/m², and (F) BMI 21.8–24.2 kg/m². (G–I) Age and predicted survival time in 7-year survival by BMI quartiles: (G) BMI <19.7 kg/m², (H) BMI 19.7–21.8 kg/m², and (I) BMI 21.8–24.2 kg/m². The highest BMI quartile (≥24.2 kg/m²) was used as the reference group. Predicted survival time and age based on BMI quartiles were modeled using a restricted cubic spline in an accelerated failure time model, adjusted for age and sex. Thick lines depict continuously adjusted predicted survival times, and the grey area reflects 95% confidence intervals for the estimates.

BMI, body mass index.

notable trends across BMI quartiles. Lower BMI was associated with poorer survival across all age groups. This effect was particularly evident in the young and older-old groups, with a not significant impact in the younger-old group. The predicted survival time increases continuously with rising BMI in the young group, but the slope of the increase slows around a BMI of 25 kg/m² in the younger-old group and plateaus after a BMI of 25 kg/m² in the

older-old group, suggesting that the benefit of a higher BMI is more pronounced in the young group compared to the younger-old and the older-old groups. Lower BMI consistently correlates with higher mortality in both short- and long-term survival analyses. The decline in survival time with increasing age in lower BMI quartiles was more pronounced in the 7-year survival analysis compared to the 2-year survival, suggesting that age plays a more signif-

icant role in long-term survival outcomes.

The major finding of this study is that, in Korea, underweight patients who underwent HD had poorer survival than obese patients, with this effect particularly pronounced in younger patients. The paradoxical relationship between a higher BMI and lower mortality, the so-called “obesity paradox,” has been widely reported in patients undergoing HD [27,28]. Most studies found the BMI-mortality association to be independent of patient age, but in those studies that did find that age had a significant effect, the findings were inconsistent [28]. For example, Vashistha et al. [12] demonstrated that higher BMI is associated with lower mortality risk across all age groups, with a stronger effect seen in incident HD patients and those younger than 65 years. Similarly, Leavey et al. [29] found that relative mortality risk decreased with increasing BMI, except in the smallest subgroup of patients who were younger than 45 years. Conversely, Inagaki et al. [30] observed a more pronounced association between higher BMI and lower mortality risk in elderly HD patients aged ≥ 65 years. Moreover, Nagai et al. [31] reported that in Japan, a high BMI was linked to improved all-cause mortality in elderly HD patients (≥ 65 years), but not in middle-aged patients (40–64 years). Even though there was a study demonstrating that the “obesity paradox” was not observed in younger ESKD patients, but observed in elderly patients. Hoo-geveen et al. [14] revealed a U-shaped association between BMI and mortality in younger ESKD patients (< 65 years), with higher mortality rates observed at both lower (< 20 kg/m²) and higher (≥ 30 kg/m²) BMI levels compared to the reference group (20–24 kg/m²). These findings suggest that the relationship between BMI and mortality in patients undergoing HD is complex and significantly influenced by age.

We identified two potential explanations for the association between lower BMI and increased mortality risk in young patients compared to the elderly. Firstly, young patients with low BMI may indicate a severe state of malnutrition, as they typically have higher BMI levels than elderly patients undergoing HD [15,23]. Reduced food intake due to poor appetite often leads to lower BMI among HD patients with malnutrition, which is strongly linked to increased mortality rates [32–34]. Secondly, young patients with low BMI may reflect lower muscle mass and increased sarcopenia compared to their elderly counter-

parts. This is because serum creatinine levels, a surrogate marker for muscle mass in HD patients, decline with age in Korea, suggesting a pronounced state of sarcopenia in young patients with lower BMI [23,35]. Sarcopenia is notably associated with elevated mortality rates in patients with ESKD [36,37].

The association between BMI and mortality remained robust to follow-up, although a lower BMI had a greater negative effect on mortality in the short term (2 years) than in the long term (overall and 7 years). Contrary to our findings, a previous study reported that lower BMI (< 23.1 kg/m²) was significantly related to higher 1-year mortality after dialysis in older patients (≥ 65 years), but after 1 year, patients with a lower BMI had similar or lower mortality risks compared to the reference BMI group (23.1–26.0 kg/m²) [38].

The strength of this study lies in its large-scale inclusion of patients, totaling 66,129 HD patients. Furthermore, to the best of our knowledge, this is the first study to evaluate the impact of age on the association between BMI and all-cause mortality in Korean HD patients. We did this by categorizing the elderly into two groups: those aged 65–74 years and those ≥ 75 years.

However, this study has several limitations that should be considered when interpreting the findings. First, there was a large amount of missing BMI data, with 74,843 of 173,216 initially included patients lacking BMI information, potentially introducing selection bias. Second, the absence of a defined threshold for high BMI prevented the analysis of patients with even higher levels of obesity. Third, smoking status, an important factor in mortality analysis, was not included because the KORDS database lacks information on the smoking habits of dialysis patients. Fourth, since the KORDS dataset provides only a single baseline BMI measurement for each patient, we were limited in our ability to assess the impact of BMI changes over time. Fifth, BMI alone does not accurately reflect obesity or underweight, as it fails to account for muscle mass, fat distribution, or skeletal structure. Future studies should consider using more precise tools like bioelectrical impedance analysis or dual-energy X-ray absorptiometry to better assess body composition.

In conclusion, our study underscores the association between lower BMI and higher mortality, which is particularly evident in younger patients, highlighting the impor-

tance of age-specific factors in HD patient management. Despite several limitations, our study provides valuable insights into the multifaceted nature of BMI-mortality associations in HD patients, emphasizing the need for further research to elucidate these complex relationships and inform clinical practice.

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Conflicts of interest

Tae Hyun Ban is the Deputy Editor of *Kidney Research and Clinical Practice* and was not involved in the review process of this article. All authors have no other conflicts of interest to declare.

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Data sharing statement

The data presented in this study are available from the corresponding author upon reasonable request.

Authors' contributions

Conceptualization: HK, YKK

Data curation: HK, SAJ, YKK

Formal analysis, Methodology: SAJ

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