Am J Transl Res 2025;17(7):5302-5319
www.ajtr.org /ISSN:1943-8141/AJTR0164882

Original Article

Impaired sleep efficiency predicts adverse prognosis in elderly pancreatic cancer patients: a retrospective case - control study based on wearable smart devices

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Received March 28, 2025; Accepted June 20, 2025; Epub July 15, 2025; Published July 30, 2025

Abstract: Background: Pancreatic cancer remains one of the most aggressive and lethal malignancies, with particularly poor prognoses in the elderly. Recent research has highlighted the role for lifestyle factors, including sleep, in cancer prognosis. This study aimed to evaluate the effect of sleep duration and quality, as measured by wearable smart devices, on the prognosis of pancreatic cancer in the elderly. Methods: This retrospective case-control study included 200 elderly patients diagnosed with stage I pancreatic cancer who underwent first-line chemotherapy and Whipple surgery. Sleep metrics were recorded using the WHOOP Strap 2.0 device, and subjective sleep quality was assessed via the Richards-Campbell Sleep Questionnaire (RCSQ) and Pittsburgh Sleep Quality Index (PSQI). Patients were divided into good and poor prognosis groups based on postoperative complications. Results: Significant differences were observed in several sleep merasures between good and poor prognosis groups. The poor prognosis group exhibited longer wake after sleep onset (27.60 ± 4.14 minutes vs. 25.90 ± 3.28 minutes, P = 0.002) and reduced sleep efficiency (75 ± 0.20% vs. 74.5 ± 0.30%, P < 0.001). Additionally, time in bed was longer in the poor prognosis group (8.76 ± 0.21 hours vs. 8.60 ± 0.18 hours, P < 0.001). In correlational analysis, sleep efficiency significantly correlated with days of hospitalization (rho = 0.724, P < 0.001). Multivariate logistic regression identified days of hospitalization (OR 6.914, P = 0.018), time in bed (OR 5.489, P = 0.012), first time out of bed (OR 4.414, P = 0.041) and sleep efficiency (OR 26.595, P < 0.001) as independent predictors of prognosis. Conclusion: Sleep duration and quality are significantly associated with prognosis in elderly pancreatic cancer patients. Continuous sleep monitoring may inform individualized care strategies to improve clinical outcomes.

Keywords: Pancreatic cancer, elderly, sleep quality, wearable devices, prognosis, chemotherapy

Introduction

Pancreatic cancer is one of the most aggressive and lethal malignancies, with a global five-year survival rate of approximately 10% [1]. Despite advances in surgical techniques, chemotherapy, and radiotherapy, the prognosis for pancreatic cancer remains poor particularly in the elderly [2]. Multiple factors affect outcomes in pancreatic cancer, including disease stage at diagnosis, the molecular and genetic characteristics of the tumor, and patient-related factors such as age and overall physiologic status [3]. Recently, lifestyle factors, including sleep, have garnered attention for their effect on cancer prognosis and overall health outcomes [4].

Sleep is a fundamental physiologic process, essential for maintaining overall health and wellbeing [5]. It is well-documented that inadequate sleep - whether in terms of duration, quality, or both - can lead to a range of health issues, including metabolic disorders, cardiovascular diseases, and impaired immune function, all of which can influence cancer progression and the patient's ability to tolerate treatment [6]. Elderly individuals are particularly vulnerable to altered sleep patterns and reduce sleep quality due to age-related changes in circadian rhythms, medical comorbidities, and polypharmacy [7]. Understanding the role of sleep in cancer prognosis is therefore crucial, as it holds may improve health outcomes through non-invasive and easily adjustable modifications [8].

https://doi.org/10.62347/SQSS8531

The use of wearable smart devices has revolutionized the ability to continuously monitor various aspects of health, including sleep [9]. These devices offer an objective, non-invasive, and cost-effective method to record sleep duration and quality over extended periods [10]. Wearable technology can capture subtle changes in sleep patterns that were not apparent in clinical settings and thus provide valuable insight into their role in disease progression [11]. In elderly patients with pancreatic cancer, real-time sleep data from wearable devices presents a novel method for associating sleep characteristics with clinical outcomes [12].

Previous studies have linked poor sleep to unfavorable tumor biology, potentially through pathways involving systemic inflammation, hormone regulation, and immune surveillance [13, 14]. However, there remains a noticeable gap in studies specifically investigating the relationship between sleep data and pancreatic cancer outcomes in the elderly. This study aimed to investigate whether sleep duration and quality, as measured by wearable smart devices, are associated with prognosis in the elderly patient with pancreatic cancer.

Materials and methods

Case selection

This study included a cohort of 200 elderly patients diagnosed with pancreatic cancer who underwent first-line chemotherapy between April 2023 and January 2024. The follow-up period for this study ranged from 6 to 36 months, with a median follow-up duration of 18 months. Demographic information, sleep duration, and other sleep quality metrics were meticulously documented in the China Sleep Big Data Center. Additionally, sleep-related data were continuously monitored and collected using wearable smart devices. The study protocol was reviewed and approved by the Institutional Review Board and Ethics Committee of Shangqiu Medical College.

Sample selection and grouping criteria

Inclusion criteria: 1) Age ≥ 60 years; 2) Pathologic confirmed diagnosis of stage I pancreatic cancer [15]; 3) Ability to read and respond to questionnaires independently; 4) Capability to self-assess sleep conditions; 5) Use of the same brand and model of wearable smart devices throughout the study period; 6) Eastern Cooperative Oncology Group (ECOG) performance status < 2; 7) Underwent Whipple surgery and received the same treatment regimen; 8) Availability of complete clinical and sleep-related data.

Exclusion criteria: 1) History of heart or renal failure; 2) Severe mental disorders; 3) Diagnosed psychiatric illness, significant cognitive impairment, or communication/language deficits; 4) Pre-existing sleep disorders such as insomnia, obstructive sleep apnea, narcolepsy, restless legs syndrome, rapid eye movement sleep behavior disorder, or circadian rhythm sleep disorders; 5) incomplete sleep data.

Prognosis evaluation

Prognosis was assessed based on the presence or absence of complications following Whipple surgery. Patients without complications were categorized into a good prognosis group. Conversely, individuals who experienced any of the following complications were categorized into a poor prognosis group: requirement for reoperation (including interventional radiology procedures), deep or organ-space surgical site infection, anastomotic leak or fistula, postoperative ileus requiring total parenteral nutrition (TPN), wound disruption, unplanned admission to the intensive care unit (ICU), sepsis, respiratory failure, or death. Diagnostic definitions and classification criteria were based on *Blumgart's Surgery of the Liver, Biliary Tract, and Pancreas* [16]. Based on these criteria, a total of 200 patients were evaluated and subsequently divided into the Good Prognosis Group (n = 106) and the Poor Prognosis Group (n = 94).

Baseline characteristics of participants and surgical procedure

At initial diagnosis, baseline information for each patient, including age, sex, height, weight, body mass index (BMI), and details of their medical and surgical history, was recorded in the China Sleep Big Data Center.

All participants underwent a standardized Whipple procedure. Preoperative preparation included a subcutaneous injection of enoxaparin sodium (Shenzhen Saboer Biopharmaceuti-

cal Co., Ltd., approval number: Z20200815) administered 12 hours before surgery, and an intravenous injection of cefuroxime (GlaxoSmithKline, approval number: H20180034) administered 0.5 to 1 hour prior to surgery. The surgical approach involved making a midline or right paramedian upper abdominal incision using an ultrasonic scalpel (Harmonic ACE + 7 Shears, Ethicon LLC, U.S.A.). Upon entering the abdominal cavity, the tumor and surrounding areas were examined. The procedure involved resection of the pancreatic head, distal stomach, duodenum, gallbladder, lower segment of the common bile duct, and part of the proximal jejunum. A stapler (Echelon Flex GST 60 mm, Ethicon LLC, U.S.A.) was then used to anastomose the remaining pancreatic stump, bile duct, and stomach with the jejunum to restore digestive tract continuity.

During the first 2-3 days post-surgery, patients received an intravenous drip of 1.5 g cefuroxime (GlaxoSmithKline, approval number: H20180034) and 10 mg metoclopramide (Shanghai Xinyi Pharmaceutical Factory Co., Ltd., approval number: S20211220) twice daily. Creon 40000 (Pfizer, approval number: F20220915) was administered orally with meals three times per day. Subcutaneous insulin (Humulin, Lilly, approval number: L20200618) was given 15 to 30 minutes before each meal at a dose of 0.1 units/kg, adjusted according to blood glucose levels. For pain management, celecoxib (Tianjin Central Pharmaceutical Co., Ltd., CAS No. 169590-42-5) was administered orally, usually twice daily. Ketorolac (Hubei Wushi Pharmaceutical Co., Ltd., approval number H20055278) was administered intravenously every six hours as needed for additional analgesia.

Preoperative clinical and laboratory data

One to two weeks prior to surgery, fasting venous blood samples were collected to obtain serum and plasma for laboratory testing. Serum levels of carcinoembryonic antigen [17] (Kit: DY7248-05, R&D Systems, Inc., USA) and carbohydrate antigen 19-9 (CA19-9) (Kit: ELH-CA19-9, RayBiotech, Inc., USA) were quantified using enzyme-linked immunosorbent assay (ELISA), with measurements performed on an Epoch 2 microplate reader (BioTek Instruments, Inc., USA). Whole blood samples were analyzed using the UniCel DxH 800 automated hematology analyzer (Beckman Coulter, Inc., USA) to determine white blood cell count (WBC), hemoglobin (Hb), and platelet count (PLT). Serum albumin levels were measured using the bromocresol green (BCG) method (Kit: DALB-250, BioAssay Systems, USA). Creatinine concentration was analyzed by the Jaffe kinetic method (Kit: C7506, Pointe Scientific, Inc., USA), and total bilirubin (TBIL) (Kit: B7506, Pointe Scientific, Inc., USA) was quantified using the diazo coupling reaction. Biochemical parameters (albumin, creatinine, and total bilirubin) were measured using the Cobas c 702 automated biochemistry analyzer (Roche Diagnostics, Germany). All procedures were strictly performed in accordance with the reagent instructions and laboratory standard operating procedures (SOPs).

Wearable smart devices

From the first day of hospitalization, all patients were equipped with the WHOOP Strap 2.0 (WHOOP Inc., Boston, MA, U.S.A.). Each night, healthcare providers ensured that the device was properly worn and functioning before sleep. Upon waking, data were automatically uploaded to the electronic medical records system's cloud platform. Sleep-related data were continuously collected from one month prior to surgery to one month before surgery. The key metrics analyzed included:

Total Sleep Time: Calculated as the interval between wake-up time and bedtime, excluding periods of nocturnal awakening.

Sleep Onset Latency: The duration between initiating sleep (in a suitable environment) and the actual onset of sleep.

Sleep Efficiency: Defined as (Total sleep time/Time in bed) × 100%.

Wake After Sleep Onset (WASO): Total duration of wakefulness occurring after initial sleep onset.

Rapid Eye Movement (REM) Sleep: A sleep phase critical for memory consolidation, emotional regulation, and cognitive processing; insufficient REM sleep may impair neurological function.

Non-Rapid Eye Movement (NREM) Sleep: A phase associated with physical restoration, immune regulation, and energy conservation; inadequate NREM sleep can compromise physiologic recovery.

Sleep Fragmentation: The frequency of sleep interruptions, which can reduce sleep continuity and degrade overall sleep quality.

Postoperative questionnaire

To comprehensively assess sleep duration and quality, postoperative questionnaires from the China Sleep Big Data Center were used to supplement data from wearable smart devices. These subjective measures showed partial correlation with objective device data.

The Richards-Campbell Sleep Questionnaire (RCSQ) employs a visual analog scale with five items, each scored from 0 (worst) to 100 (best). The Cronbach's alpha of the RCSQ was 0.923 [18].

The Pittsburgh Sleep Quality Index (PSQI) evaluates sleep quality across seven components, each scored from 0 (no difficulty) to 3 (severe difficulty). The sum of these component scores yields a total score ranging from 0 to 21. A lower total score indicates better sleep quality, with a total score of 5 or more generally indicating poor sleep quality. The PSQI has a Cronbach's alpha of 0.78 [19].

Assessment of survival outcomes

Overall survival (OS) was defined as the interval from pancreatic cancer diagnosis to the death from any cause or last follow-up. For surviving patients, the survival time was censored accordingly. Death dates were verified through the China Sleep Big Data Center. In cases that were lost to follow-up, the last clinical visit date was used as the censoring time.

Progression-free survival (PFS) was defined as the time from Whipple surgery to documented disease progression (including local recurrence or distant metastasis) or death from any cause. Disease progression was assessed by imaging results (CT or MRI), using the Response Evaluation Criteria in Solid Tumors (RECIST 1.1) criteria [20]. Patients without disease progression and still alive at last imaging follow-up were censored at that time. Imaging and clinical assessment results were evaluated by an attending physician.

Primary outcomes included postoperative complications as defined in Section 2.3, serving as the primary prognostic indicator, alongside survival outcomes (OS and PFS). Objective sleep parameters measured by the WHOOP Strap 2.0 encompassed sleep efficiency (%), time in bed (hours), and wake after sleep onset (minutes). Secondary outcomes comprised subjective sleep quality assessments (RCSQ and PSQI scores), physiological sleep architecture parameters (REM and NREM sleep durations and sleep fragmentation index), and laboratory biomarkers such as CA19-9 levels, serum albumin, and hemoglobin.

Statistical analysis

Data analysis was conducted using SPSS 29.0 (SPSS Inc., Chicago, IL, USA). Categorical data were expressed as [n (%)], and group comparisons were conducted using the chi-square test. Continuous variables were subjected to normality testing using the Shapiro-Wilk method. Data following a normal distribution were reported as means and standard deviations ($X \pm s$), while non-normally distributed data were analyzed using the Wilcoxon rank-sum test and reported as medians with interquartile ranges [median (25% quantile, 75% quantile)]. For group comparisons of continuous variables, Student's t-test was used for normally distributed data, while the Mann-Whitney U test was applied for non-normally distributed data. A *P*-value of less than 0.05 was considered significant.

OS and PFS were analyzed using Kaplan-Meier survival analysis, and differences between groups were assessed using the log-rank test. In the multivariate logistic regression analysis, variables were coded based on their measurement scale and clinical relevance. Binary variables (e.g., gender, reoperation) were coded as 0 (absence/reference category) and 1 (presence). Continuous variables (e.g., sleep efficiency, time in bed) were entered as continuous variables without categorization. Ordinal categorical variables were treated as ordered factors, while nominal variables were dummy-coded. Sleep parameters derived from wearable devices were analyzed as continuous variables. Survival outcomes were included as time-to-event covariates.

Table 1. Baseline characteristics of participants

Data	Good Prognosis Group (n = 106)	Poor Prognosis Group (n = 94)	t/χ^2	P
Age (years)	75.60 ± 7.23	75.63 ± 7.54	0.034	0.973
Gender, n (%)			1.285	0.257
Male	64 (60.38)	64 (68.09)		0.507
Female	42 (39.62)	30 (31.91)		
Education, n			1.527	0.466
Junior high school	25 (23.58)	18 (19.15)		
Senior high school and middle special school	64 (60.38)	55 (58.51)		
Junior college, college graduate, and above	17 (16.04)	21 (22.34)		
Tumor location, n (%)			2.824	0.244
Head and/or uncinate process	75 (70.75)	60 (63.83)		
Neck	13 (12.26)	9 (9.57)		
Body and/or tail	18 (16.98)	25 (26.6)		
Weight loss, n (%)	53 (50)	48 (51.06)	0.023	0.881
Jaundice, n (%)	0 (0)	2 (2.13)	0.636	0.425
Nausea, n (%)	5 (4.72)	2 (2.13)	0.371	0.543
Abdominal pain and distension, n (%)	54 (50.94)	49 (52.13)	0.028	0.867
Alcohol Consumption			0.092	0.761
Yes	24 (22.64)	23 (24.47)		
No	82 (77.36)	71 (75.53)		
Tobacco Consumption			2.133	0.144
Yes	19 (17.92)	10 (10.64)		
No	87 (82.08)	84 (89.36)		
Previous Surgeries			0.023	0.881
Yes	53 (50.00)	46 (48.94)		
No	53 (50.00)	48 (51.06)		
Physical activity, n (%)	76 (71.70)	63 (67.02)	0.514	0.473
Tumor size, cm	1.60 ± 0.60	1.70 ± 0.40	1.502	0.135

To further explore the relationship between sleep quality and patient prognosis, we performed a correlation analysis between key metrics (including sleep duration, sleep efficiency, PSQI scores, RCSQ scores) and prognosis.

Multicollinearity was assessed using variance inflation factors (VIF). Based on the final multivariate logistic regression model, a nomogram was constructed using the rms package in R software (version 4.3.3). Each predictor's score was proportionally assigned according to the standardized regression coefficients, and the total score was used to estimate the probability of adverse outcomes.

To evaluate the predictive performance of the nomogram, we calculated the area under the receiver operating characteristic (ROC) curve (AUC). The ROC curve illustrates the trade-off between sensitivity and specificity across various thresholds. Additionally, decision curve analysis (DCA) was performed to assess the clinical utility of the nomogram by comparing the net benefit of using the nomogram versus alternative strategies. Calibration curves were generated to assess the agreement between predicted probabilities and observed outcomes. These curves provide insight into how well the nomogram's predictions align with actual patient outcomes.

Results

Baseline characteristics of participants

This retrospective case-control study analyzed baseline characteristics of 200 participants, divided into a good prognosis group (n = 106) and a poor prognosis group (n = 94) (**Table 1**).

Table 2. Preoperative clinical and laboratory data

Data	Good Prognosis Group (n = 106)	Poor Prognosis Group (n = 94)	t	P
CEA, ng/mL	2.15 ± 0.72	2.29 ± 0.70	1.398	0.164
CA19-9, U/mL	15.35 ± 5.45	16.30 ± 5.88	1.185	0.237
WBC, cells/μL	5785.01 ± 1731.67	5820.88 ± 1665.28	0.149	0.882
Hemoglobin, g/dL	12.75 ± 1.43	12.40 ± 1.56	1.647	0.101
Albumin, g/dL	4.10 ± 0.23	4.05 ± 0.33	1.283	0.201
Creatinine, mg/dL	0.66 ± 0.27	0.71 ± 0.25	1.459	0.146
Total bilirubin, mg/dL	0.65 ± 0.22	0.66 ± 0.18	0.247	0.805
Platelet, $\times 10^4$/μL	21.26 ± 6.05	19.95 ± 5.78	1.568	0.119

CEA: Carcinoembryonic Antigen; CA19-9: carbohydrate antigen 19-9; WBC: White Blood Cell.

The mean age was comparable between groups (75.60 ± 7.23 vs. 75.63 ± 7.54 years, P = 0.973). Gender distribution did not significantly differ (P = 0.257), with males constituting 60.38% of the good prognosis group and 68.09% of the poor prognosis group. Educational background was comparable across groups. Tumor location showed variability but did not reach statistical significance, as did other clinical symptoms such as weight loss, jaundice, nausea, and abdominal pain. Lifestyle factors, including alcohol and tobacco consumption, as well as prior surgical history, showed no significant associations with prognosis. Physical activity level was slightly higher in the good prognosis group, though this difference was not statistically significant. Tumor size was marginally smaller in the good prognosis group, though this difference was similarly non-significant. Overall, baseline characteristics demonstrated no significant disparities between the good and poor prognosis groups across various demographic and clinical metrics.

Preoperative clinical and laboratory data

No significant differences were observed between groups for routine preoperative clinical and laboratory indicators, including tumor markers, inflammation and metabolic parameters (all P > 0.05) (**Table 2**). Serum CEA and CA19-9 levels were slightly higher in the poor prognosis group compared to the good prognosis group, but the differences did not reach statistical significance. WBC count, hemoglobin, albumin, and platelet counts were also comparable between the two groups (all P > 0.05). Similarly, the levels of creatinine and total bilirubin showed no significant intergroup differences (all P > 0.05).

Intraoperative and postoperative characteristics

The length of hospital stay was considerably greater in the poor prognosis group, with 51.06% staying ≥ 16 days compared to only 6.6% in the good prognosis group (P < 0.001) (**Table 3**). Additionally, pancreatic consistency differed significantly, with a higher prevalence of soft pancreas in the poor prognosis group (P = 0.007). The time to first ambulation postoperatively was earlier in the good prognosis group than in the poor prognosis group (P = 0.01). Although differences in reoperation rates approached significance (P = 0.051), no significant differences were found in other parameters: operative time, blood loss, days in ICU, and analgesic dosage. These findings suggest that certain intraoperative and postoperative factors were associated with prognosis in elderly pancreatic cancer patients.

Sleep quality and sleep duration

WASO time was significantly shorter in the good prognosis group compared to the poor prognosis group (P = 0.002) (**Table 4**). Sleep onset latency was also significantly shorter in the good prognosis group than in the poor prognosis group (P = 0.024). Sleep efficiency showed a marked difference, with the good prognosis group showing a higher efficiency (P < 0.001). Furthermore, time in bed was significantly shorter in the good prognosis group (8.60 ± 0.18 hours) versus the poor prognosis group (8.76 ± 0.21 hours) (P < 0.001). Although total sleep time was marginally longer in the poor prognosis group, this difference did not reach statistical significance. These findings suggest that certain sleep indicators measured via wearable devices were significantly associated

Table 3. Intraoperative and postoperative characteristics

Measurement	Good Prognosis Group (n = 106)	Poor Prognosis Group (n = 94)	t/χ^2	P
Operative Time, n (%)			0.035	0.851
≥ 4 hours	101 (95.28)	91 (96.81)		
< 4 hours	5 (4.72)	3 (3.19)		
Blood Loss, n (%)			1.938	0.164
≥ 1000 cc	10 (9.43)	15 (15.96)		
< 1000 cc	96 (90.57)	79 (84.04)		
Reoperation, n (%)			3.807	0.051
Yes	0 (0)	5 (5.32)		
No	106 (100)	89 (94.68)		
Days of Hospitalization, n (%)			49.394	< 0.001
≥ 16 days	7 (6.6)	48 (51.06)		
< 16 days	99 (93.4)	46 (48.94)		
Days in ICU, n (%)			1.961	0.161
≥ 4 days	36 (33.96)	41 (43.62)		
< 4 days	70 (66.04)	53 (56.38)		
Pancreatic Consistency, n (%)			7.405	0.007
Soft	52 (49.06)	64 (68.09)		
Firm	54 (50.94)	30 (31.91)		
Analgesic Dosage (mg/kg)	31.41 ± 12.03	35.27 ± 17.52	1.793	0.075
First time out of bed (days)	3.36 ± 1.81	4.13 ± 2.32	2.591	0.010

ICU: Intensive Care Unit.

Table 4. Sleep duration metrics collected by wearable smart devices

Item	Good Prognosis Group (n = 106)	Poor Prognosis Group (n = 94)	t/χ^2	P
Wake after sleep onset, minutes	25.90 ± 3.28	27.60 ± 4.14	3.202	0.002
Sleep onset latency, minutes	28.50 ± 2.85	29.45 ± 3.02	2.277	0.024
Total sleep time, h	6.85 ± 0.17	6.89 ± 0.15	1.768	0.079
Time in bed, h	8.60 ± 0.18	8.76 ± 0.21	5.498	< 0.001
Sleep efficiency, %	75.01 ± 0.20	74.50 ± 0.30	13.917	< 0.001

with prognosis in elderly pancreatic cancer patients.

REM sleep duration was significantly longer in the good prognosis group compared to the poor prognosis group (P = 0.030) (**Figure 1**). Similarly, the NREM sleep duration was significantly longer in the good prognosis group (P = 0.024). Sleep fragmentation, measured as events per hour, was lower in the good prognosis group (P = 0.011). No significant differences were observed in respiratory rate or heart rate variability between groups. These findings highlight the relevance of sleep quality components to the prognosis in elderly pancreatic cancer patients.

Postoperative questionnaire

According to the RCSQ, participants in good prognosis group reported significantly better subjective sleep quality, with higher scores on postoperative days 1, 3, and 7 compared to the poor prognosis group (**Table 5**). Although PSQI scores on postoperative day 1 showed no significant difference between groups, scores were higher in the good prognosis group on postoperative days 3 and 7 versus the poor prognosis group, with difference on postoperative day 3 approaching significant level (P = 0.049) and on day 7 reaching significant level (P = 0.001). These results highlight the close association between objective sleep metrics

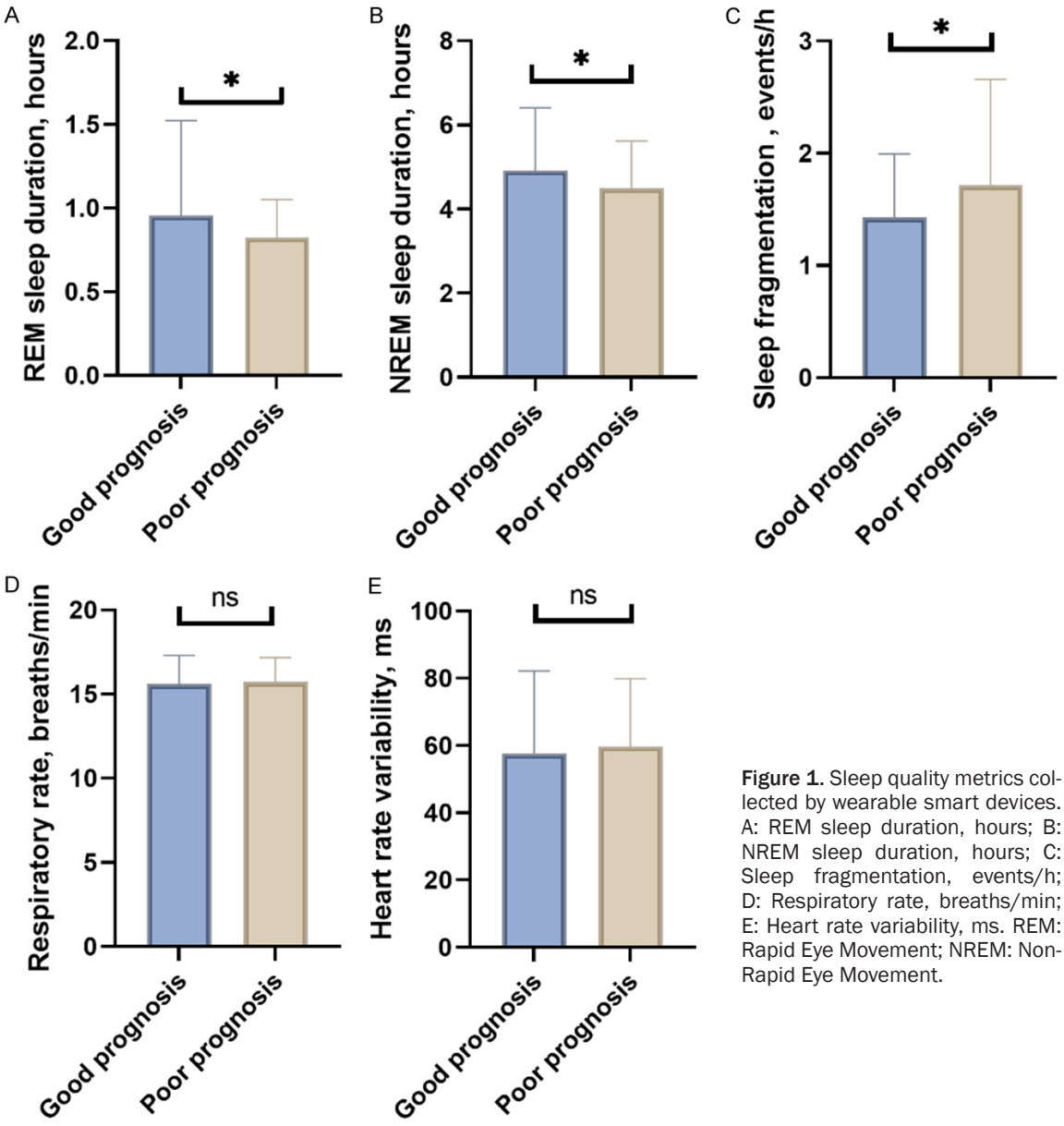

Figure 1. Sleep quality metrics collected by wearable smart devices. A: REM sleep duration, hours; B: NREM sleep duration, hours; C: Sleep fragmentation, events/h; D: Respiratory rate, breaths/min; E: Heart rate variability, ms. REM: Rapid Eye Movement; NREM: Non-Rapid Eye Movement.

Table 5. Postoperative questionnaire

Item	Good Prognosis Group (n = 106)	Poor Prognosis Group (n = 94)	t/χ^2	P
RCSQ				
Postoperative 1d	31.62 ± 13.70	25.84 ± 12.02	3.176	0.002
Postoperative 3d	24.22 ± 13.07	19.21 ± 10.12	3.005	0.003
Postoperative 7d	19.82 ± 10.32	15.63 ± 7.30	3.279	0.001
PSQI				
Postoperative 1d	8.51 ± 1.32	8.45 ± 2.33	0.214	0.831
Postoperative 3d	7.90 ± 1.45	8.42 ± 2.13	1.987	0.049
Postoperative 7d	6.50 ± 1.10	7.20 ± 1.80	3.258	0.001

RCSQ: Richards-Campbell Sleep Questionnaire; PSQI: Pittsburgh Sleep Quality Index.

and prognosis among elderly pancreatic cancer patients during the postoperative period.

Survival analysis

Survival analysis revealed significant differences in OS (**Figure 2**) and PFS (**Figure 3**) between the good prognosis group and the poor prognosis group. The median OS in the good prognosis group was 24.05 months, significantly

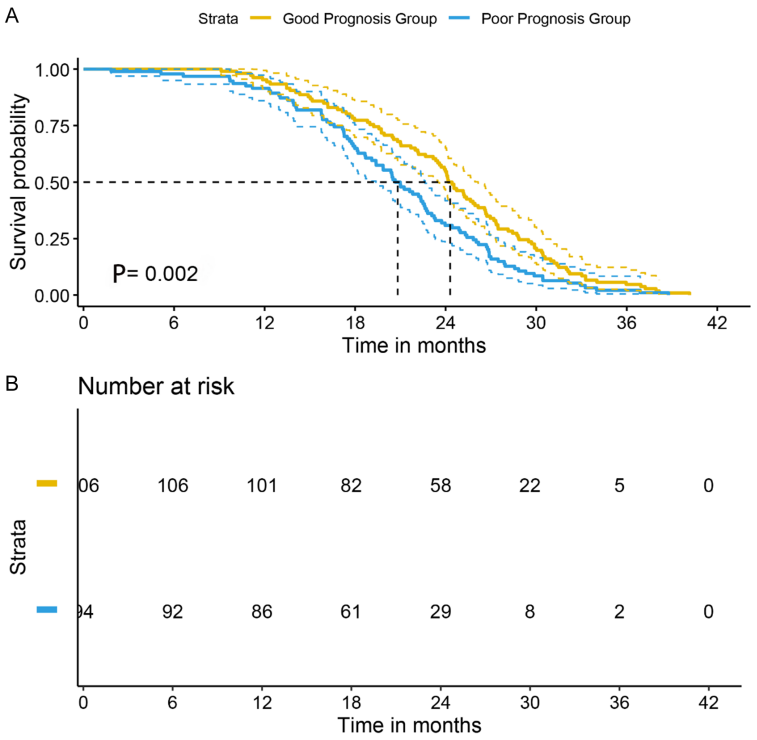

Figure 2. OS Curves between two groups. A: Kaplan-Meier Survival Curve; B: Number at Risk Table. OS: Overall Survival.

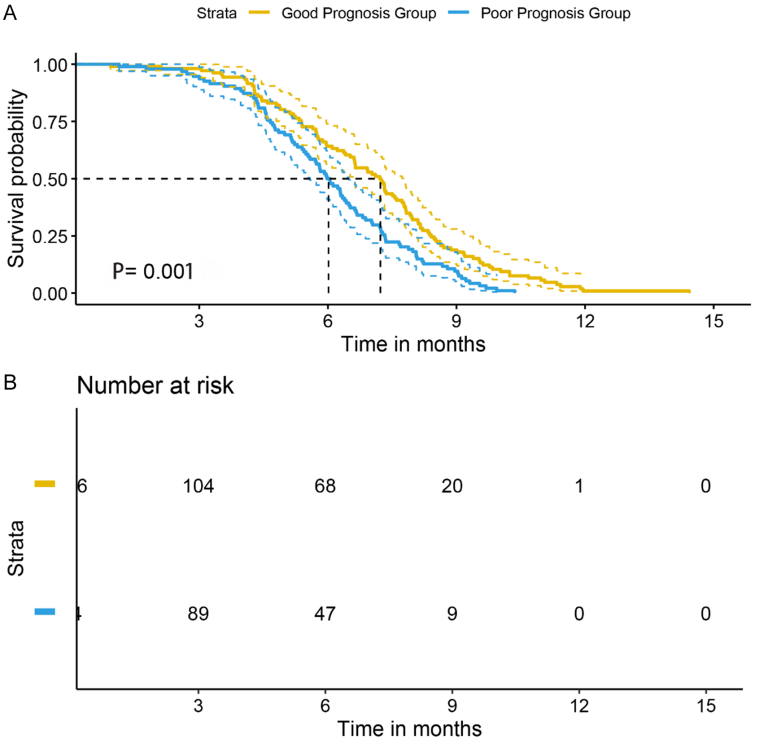

Figure 3. PFS Curves between two groups. A: Kaplan-Meier Survival Curve; B: Number at Risk Table. PFS: Progression-Free Survival.

longer than 20.91 months in the poor prognosis group. Kaplan-Meier survival curves confirmed this difference (P = 0.002). Similarly, median PFS was 7.06 months in the good prognosis group, significantly longer than 6.08 months in the poor prognosis group (P = 0.001).

Correlation analysis

Correlation analysis showed that prognosis was significantly associated with various clinical and sleep data. Softer pancreatic texture (rho = 0.192, P = 0.006) (**Figure 4**) and delayed first postoperative ambulation (rho = 0.164, P = 0.021) were weakly positively correlated with poor prognosis. Among sleep indicators, WASO (rho = 0.222, P = 0.002), SOL (rho = 0.163, P = 0.021), and sleep fragmentation events per hour (rho = 0.144, P = 0.042) were all positively correlated with poor prognosis. In contrast, NREM sleep duration was negatively correlated with poor prognosis (rho = -0.161, P = 0.023). REM sleep duration was not significantly associated with poor prognosis (P = 0.101). Postoperative RCSQ is negatively correlated with poor prognosis, while postoperative PSQI is positively correlated with poor prognosis (RCSQ: rho = -0.208 - -0.207, P ≤ 0.006; PSQI: rho = 0.161-0.239, P ≤ 0.022). Additionally, poor prognosis was significantly associated with worse survival outcomes, with both OS (rho = -0.221, P = 0.002) and PFS (rho = -0.210, P = 0.003) negatively correlated with poor prognosis.

Logistic regression analysis

Univariate logistic regression analysis identified several key

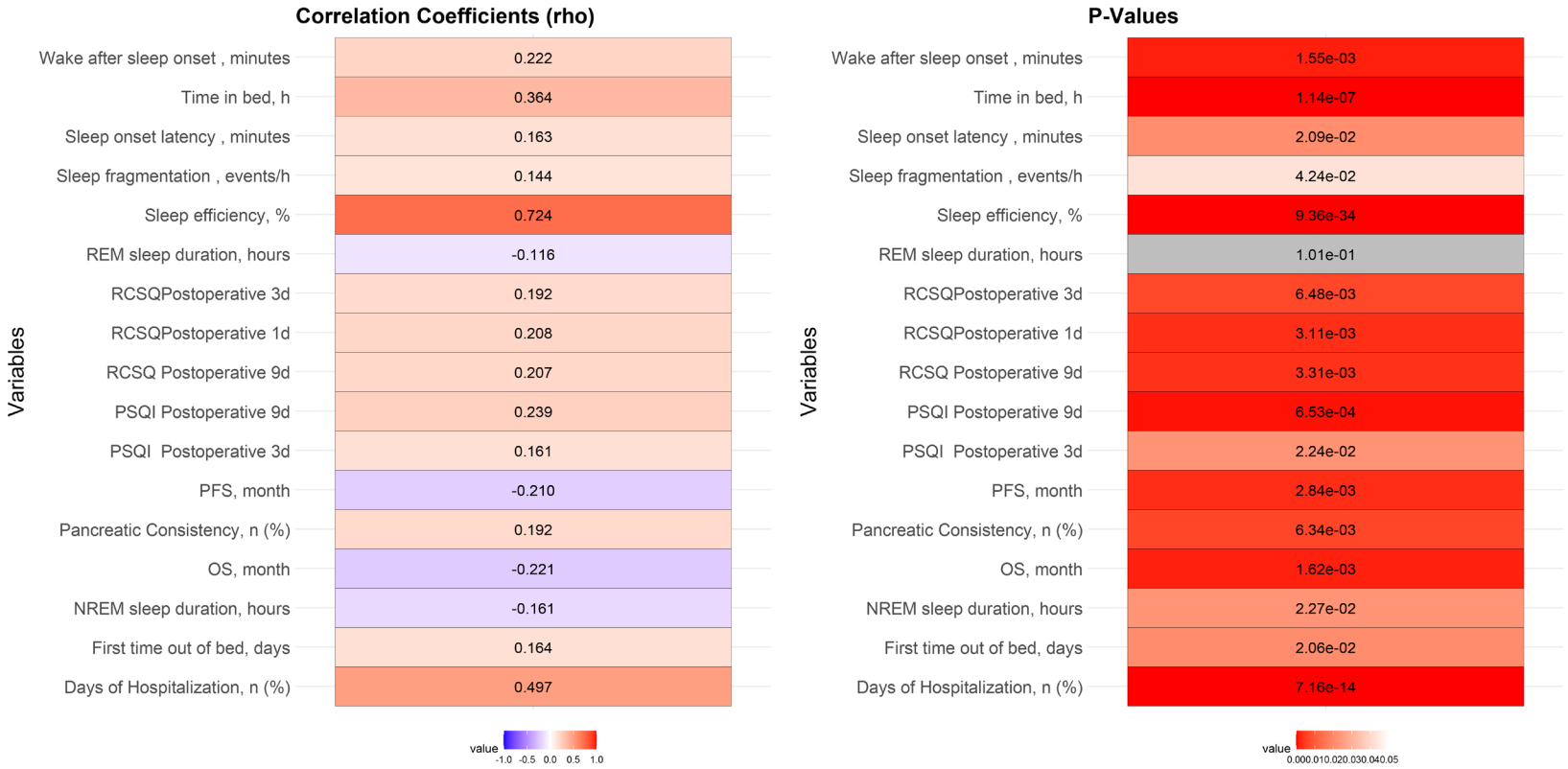

Figure 4. Correlation analysis of sleep duration and quality with prognosis in elderly patients with pancreatic cancer. REM: Rapid Eye Movement; NREM: Non-Rapid Eye Movement; RCSQ: Richards-Campbell Sleep Questionnaire; PSQI: Pittsburgh Sleep Quality Index; OS: Overall Survival; PFS: Progression-Free Survival.

Table 6. Univariate logistic regression analysis of the impact of sleep duration and quality on prognosis in elderly patients with pancreatic cancer

Item	Coefficient	Std Error	Wald	P	OR (95% CI)
Days of Hospitalization, n (%)	2.692	0.442	6.087	< 0.001	14.758 (6.566-38.004)
Pancreatic Consistency, n (%)	0.795	0.294	2.701	0.007	2.215 (1.251-3.976)
First time out of bed (days)	0.181	0.071	2.560	0.010	1.198 (1.046-1.381)
Wake after sleep onset, minutes	0.125	0.040	3.101	0.002	1.133 (1.049-1.230)
Sleep onset latency, minutes	0.111	0.050	2.23	0.026	1.117 (1.015-1.235)
Time in bed, h	3.960	0.822	4.818	< 0.001	52.438 (11.204-284.31)
Sleep efficiency, %	7.642	1.042	7.333	< 0.001	2084.187 (322.741-19665.04)
REM sleep duration, hours	-0.685	0.333	2.056	0.040	0.504 (0.257-0.956)
NREM sleep duration, hours	-0.241	0.110	2.198	0.028	0.786 (0.630-0.970)
Sleep fragmentation, events/h	0.493	0.193	2.558	0.011	1.637 (1.131-2.418)
RCSQ Postoperative 1 d	-0.035	0.012	3.051	0.002	1.036 (1.013-1.060)
RCSQ Postoperative 3 d	-0.037	0.013	2.932	0.003	1.038 (1.013-1.065)
RCSQ Postoperative 7 d	-0.054	0.017	3.182	0.001	1.055 (1.022-1.092)
PSQI Postoperative 3 d	0.162	0.081	1.997	0.046	1.176 (1.006-1.386)
PSQI Postoperative 7 d	0.332	0.105	3.158	0.002	1.394 (1.143-1.730)
OS, month	-0.066	0.022	-3.073	0.002	0.936 (0.896-0.975)
PFS, month	-0.218	0.070	-3.089	0.002	0.805 (0.697-0.920)

REM: Rapid Eye Movement; NREM: Non-Rapid Eye Movement; RCSQ: Richards-Campbell Sleep Questionnaire; PSQI: Pittsburgh Sleep Quality Index; OS: Overall Survival; PFS: Progression-Free Survival.

sleep-related indicators as significant predictors of prognosis in elderly pancreatic cancer patients (**Table 6**). Prolonged hospitalization was strongly associated with increased odds of poor prognosis (OR = 14.758, 95% CI: 6.566-38.004, P < 0.001). Similarly, longer time spent in bed (OR = 52.438, 95% CI: 11.204-284.31, P < 0.001) and reduced sleep efficiency (OR = 26.595, 95% CI: 3.227-219.654, P < 0.001) were highly predictive of poor prognosis. Increased sleep fragmentation significantly raised poor prognosis risk (OR = 1.637, 95% CI: 1.131-2.418, P = 0.011), as did longer wake after sleep onset (OR = 1.133, P = 0.002) and prolonged sleep onset latency (OR = 1.117, P = 0.026). Conversely, longer REM (OR = 0.504, 95% CI: 0.257-0.956, P = 0.040,) and NREM (OR = 0.786, 95% CI: 0.630-0.970, P = 0.028) sleep durations were protective factors for prognosis. Postoperative sleep quality scores, as indicated by RCSQ and PSQI, significantly correlated prognosis across several time points, suggesting that improved sleep quality correlates with better outcomes. Additionally, delayed first ambulation (P = 0.010) and soft pancreatic texture (P = 0.007) were also linked to worse outcomes. Survival times showed a protective effect on prognosis: each additional month of OS reduced poor prognosis risk by 6.4% (OR = 0.936, 95% CI: 0.896-0.975, P = 0.002), and each month increase in PFS decreased risk by 19.5% (OR = 0.805, 95% CI: 0.697-0.920, P = 0.002). These results suggest that the protective effects of sleep-related parameters on survival outcomes are independent of other confounding factors.

Variables with P < 0.10 in univariate analysis and clinical relevance were included in the multivariate logistic regression model (**Table 7**). After adjustment for confounders, prolonged days of hospitalization (OR = 6.914, 95% CI: 1.396-34.252, P = 0.018), delayed first postoperative ambulation (OR = 4.414, 1.063-18.339, P = 0.041), increased time in bed (OR = 5.489, 1.448-20.802, P = 0.012), and higher RCSQ score on postoperative day 9 (OR = 5.456, 1.050-28.341, P = 0.044) were identified as independent risk factors for poor prognosis. Sleep efficiency emerged as the strongest protective factor, with each 1% increase reducing the risk of poor prognosis by 97.3% (OR = 0.038, corresponding sleep efficiency OR = 26.595, P < 0.001). Additionally, extended OS was significantly associated with reduced poor prognosis risk (OR = 0.158, 95% CI: 0.039-0.640, P = 0.010).

Table 7. Multivariate logistic regression analysis of the impact of sleep duration and quality on prognosis in elderly patients with pancreatic cancer

Item	Coefficient	Std Error	Wald Stat	P	OR (95% CI)
Days of Hospitalization, n (%)	1.934	0.816	2.368	0.018	6.914 (1.396-34.252)
Pancreatic Consistency, n (%)	0.097	0.691	0.141	0.888	1.102 (0.284-4.272)
First time out of bed (days)	1.485	0.727	2.044	0.041	4.414 (1.063-18.339)
Wake after sleep onset, minutes	1.416	0.731	1.937	0.053	4.121 (0.983-17.268)
Sleep onset latency, minutes	-0.005	0.685	-0.008	0.994	0.995 (0.260-3.810)
Time in bed, h	1.703	0.680	2.505	0.012	5.489 (1.448-20.802)
Sleep efficiency, %	3.281	0.757	4.336	< 0.001	26.595 (6.036-117.170)
REM sleep duration, hours	-18.441	1463.395	-0.013	0.990	0.000 (0.000-Inf)
NREM sleep duration, hours	-1.348	0.934	-1.442	0.149	0.260 (0.042-1.622)
Sleep fragmentation, events/h	1.610	0.839	1.920	0.055	5.005 (0.967-25.915)
RCSQ Postoperative 1 d	-0.145	0.692	0.210	0.834	1.156 (0.298-4.489)
RCSQ Postoperative 3 d	-0.125	0.867	0.144	0.886	1.133 (0.207-6.200)
RCSQ Postoperative 7 d	-1.697	0.841	2.018	0.044	5.456 (1.050-28.341)
PSQI Postoperative 3 d	0.579	0.858	0.674	0.500	1.783 (0.332-9.580)
PSQI Postoperative 7 d	1.589	0.872	1.822	0.068	4.898 (0.886-27.068)
OS, month	-1.848	0.715	-2.585	0.010	0.158 (0.039-0.640)
PFS, month	-0.182	0.735	0.248	0.804	1.200 (0.284-5.065)

REM: Rapid Eye Movement; NREM: Non-Rapid Eye Movement; RCSQ: Richards-Campbell Sleep Questionnaire; PSQI: Pittsburgh Sleep Quality Index; OS: Overall Survival; PFS: Progression-Free Survival.

Several variables showed borderline significance trends: WASO (OR = 4.121, P = 0.053), sleep fragmentation (OR = 5.005, P = 0.055), and PSQI on postoperative day 9 (OR = 4.898, P = 0.068). REM sleep duration could not yield reliable conclusions due to an overly wide confidence interval (0.000-Inf), likely affected by extreme values or model convergence issues. Other variables such as pancreatic texture, sleep onset latency, NREM sleep duration, and early recovery scores did not retain significance after adjustment (all P > 0.05).

Nomogram validation

A prognostic nomogram was developed to visually estimate the likelihood of poor prognosis in elderly pancreatic cancer patients, integrating key sleep-related parameters, including based on sleep duration and quality (**Figure 5A**). The model's discriminative ability was evaluated using a receiver operating characteristic (ROC) curve, which demonstrated excellent performance with an area under the curve (AUC) of 0.961, indicating high predictive accuracy (**Figure 5B**). Calibration of the nomogram was assessed using a calibration curve (**Figure 5C**), which demonstrated good agreement between the predicted probabilities and actual observed outcomes. The curve closely followed the ideal 45-degree line, suggesting that the model accurately predicts patient outcomes across the range of predicted probabilities. Specifically, at lower risk thresholds, the nomogram slightly overestimated the probability of adverse outcomes, while at higher thresholds, it provided a more accurate prediction. This indicates that the nomogram was well-calibrated and reliable for clinical use. Finally, the clinical utility of the nomogram was evaluated using decision curve analysis (**Figure 5D**). The net benefit of using the nomogram was compared against the treat-all and treat-none strategies across a wide range of threshold probabilities. The results showed that the nomogram provided a higher net benefit than both the treat-all and treat-none approaches, particularly within the probability range of 0.1 to 0.4. This suggests that the nomogram offers valuable clinical utility by helping clinicians make more informed decisions regarding patient management.

Discussion

A critical observation from our study was the clear distinction in sleep patterns between patients with good and poor prognoses. Specifically, shorter wake after sleep onset times

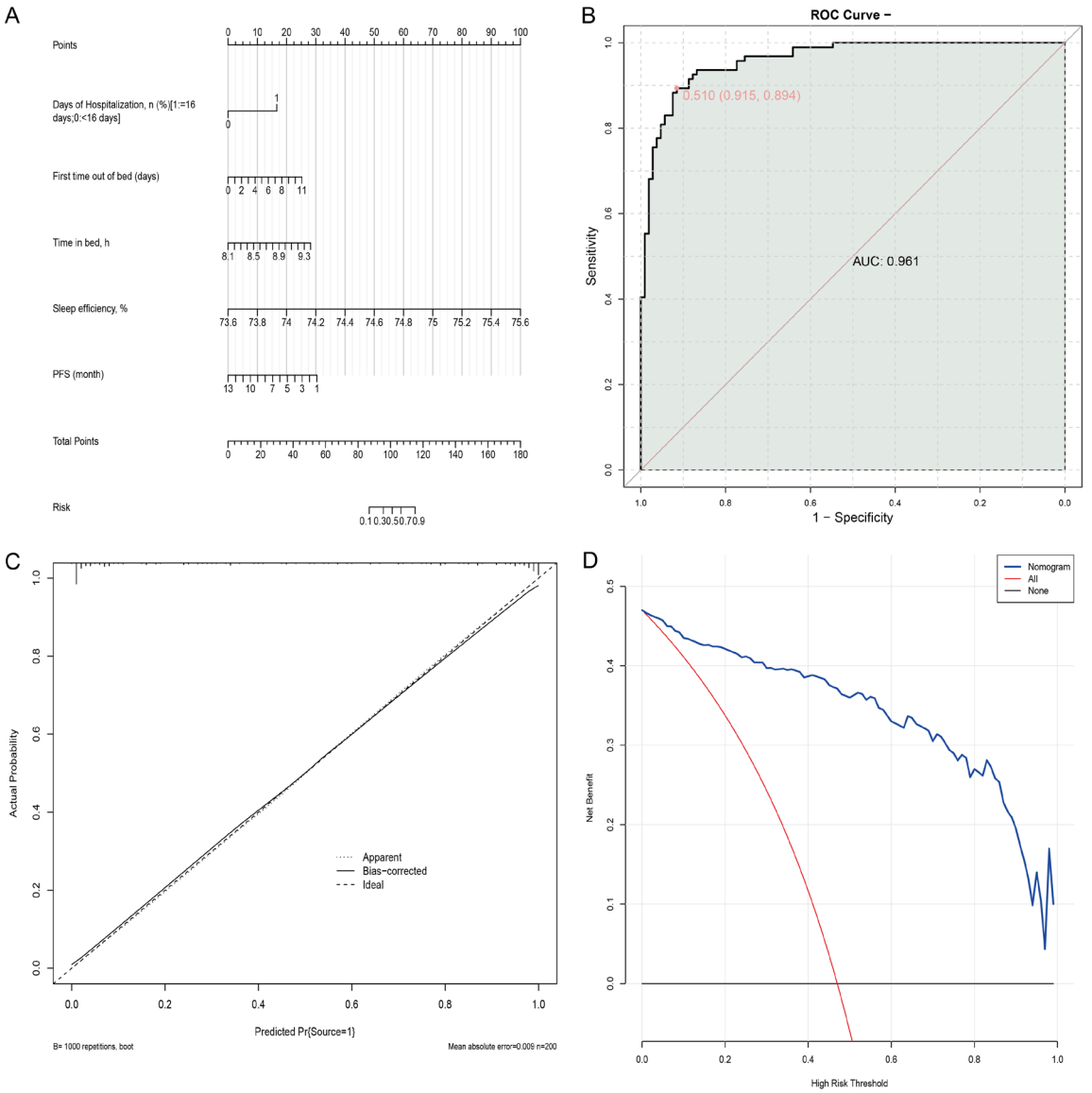

Figure 5. Nomogram for effectof sleep duration and quality on prognosis in elderly patients with pancreatic cancer. A: Nomogram; B: ROC Curve; C: Calibration Curve; D: Decision Curve. ROC: Receiver Operating Characteristic; PFS: Progression-Free Survival.

and reduced sleep fragmentation were prominent in the good prognosis group. These findings suggest that uninterrupted sleep might play a crucial role in enhancing the restorative physiologic processes essential for recovery in elderly patients. Disrupted sleep has been linked to various physiological detriments, including impaired immune responses and reduced cellular repair mechanisms [21, 22]. In pancreatic cancer, where the immune system plays a pivotal role in suppressing tumor progression, poor sleep could diminish the body's antitumor response [23].

Shorter sleep onset latency, observed in the good prognosis group, aligns with existing literature [24, 25], indicating that prolonged latency is a predictor of compromised sleep quality and is frequently associated with reductions in both REM and NREM sleep durations. These two sleep phases serve critical roles: REM sleep is implicated in cognitive functions such as memory consolidation and emotional regulation, while NREM sleep is pivotal for physical restoration and immune function. Our data revealed that extended durations of both REM and NREM sleep were associated with favorable

prognoses, suggesting that enhanced sleep phases potentially facilitate improved cognitive and emotional states, bolstering patients' overall capacity to endure and respond to cancer therapies.

Interestingly, increased time in bed was associated with poorer prognosis. While extended time in bed typically correlates with more rest, in our study, it may indicate fragmented sleep or difficulty achieving deep sleep stages, commonly seen in patients with underlying anxiety, depression, or discomfort due to disease or postoperative states [26, 27]. This is supported by our findings of associations between increased time in bed, delayed first ambulation post-surgery and adverse outcomes in surgical recoveries. Early mobilization has been consistently shown to accelerate recovery by improving circulation, reducing the risk of thrombosis, and promoting physical function in elderly surgical populations [28, 29].

Moreover, the negative correlations observed between hospital stay and both OS and PFS suggest that prolonged hospitalization may be a marker of underlying disease severity or suboptimal recovery, which in turn adversely affects long-term outcomes. Reducing hospital stay through targeted interventions (e.g., enhanced recovery after surgery [ERAS] protocols) may not only improve short-term recovery but also confer long-term survival benefits [30].

Our data showed that increased sleep efficiency was linked to a better prognosis. Sleep efficiency, defined as the proportion of time spent asleep relative to time spent in bed, reflects not only sleep quality but also the quality of sleep continuity. High sleep efficiency indicates less time awake after sleep onset, correlating with less disruption and greater continuity of sleep [31]. Sleep quality, often measured by efficiency, directly influences physiological recovery processes, affecting cytokine production, stress hormone regulation, and, consequently, tumor micro-environment adaptations that may affect tumor progression and patient resilience [32, 33].

Correlations between sleep quality metrics like those from the RCSQ and the PSQI also underscore that subjective perceptions of sleep, alongside objective measures, are critical for predicting patient outcomes. These tools capture patients' psychosocial and emotional experiences of sleep, which significantly impact mood, pain thresholds, and motivation-factors that are essential to postoperative compliance, physical rehabilitation, and overall recovery [34, 35].

Interestingly, the logistic regression analysis identified postoperative day indicators as key predictors of outcomes, highlighting the dynamic and evolving influence of sleep patterns and recovery interactions over time. This aspect emphasizes the potential for targeted interventions at various recovery stages, aiming to optimize sleep as a therapeutic modality.

The molecular mechanisms underlying sleep and its effect on cancer progression also provide a plausible framework to interpret our findings. The circadian regulation involving melatonin has demonstrated effects in enhancing immune surveillance and inhibiting cancer cell proliferation [36]. Disrupted sleep patterns could potentially attenuate these protective mechanisms, thereby influencing prognosis adversely [37]. Furthermore, sleep disturbances have been implicated in dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis, leading to altered cortisol secretion. Elevated cortisol levels might exacerbate inflammatory processes and disrupt regular immune functioning [38].

In both univariate and multivariate analyses, the PSQI score on postoperative day 9 emerged as a critical predictor of prognosis. This finding highlights the clinical value of integrating sleep quality assessments into perioperative care protocols. Interventions designed to improve subjective and objective sleep quality, such as cognitive-behavioral therapy for insomnia (CBTI), melatonin supplementation, and environmental modification, may yield substantial benefits. These interventions should be incorporated into comprehensive cancer care strategies, particularly for elderly populations. Although objective metrics such as sleep efficiency proved highly predictive of outcomes, the discrepancy observed between subjective (e.g., PSQI) and objective (wearable device) assessments suggests a potential perceptual bias in how patients evaluate their sleep. The negative associations observed between overall survival (OS) and progression-free survival (PFS) with

poor prognosis risk further validate the prognostic value of sleep-related parameters. Specifically, our correlation analysis revealed that both shorter OS and PFS were significantly associated with poorer sleep quality metrics such as lower sleep efficiency and higher PSQI scores. These findings suggest that sleep-related metrics can serve as robust indicators of both short-term and long-term survival outcomes. In terms of short-term survival benefits, reduced sleep efficiency and increased PSQI scores were predictive of worse postoperative recovery and a higher likelihood of complications. This is consistent with previous studies indicating that poor sleep quality can impair immune function and delay wound healing, leading to prolonged hospital stays and increased morbidity. For long-term survival benefits, the strong positive correlations between sleep duration and sleep efficiency with both OS and PFS highlight the importance of maintaining good sleep quality over the course of treatment. Patients with better sleep quality experienced longer survival times, suggesting that interventions aimed at improving sleep could potentially improve long-term outcomes. These findings suggest that improving sleep quality and efficiency may not only enhance short-term recovery but also confer long-term survival benefits, potentially through mechanisms such as immune modulation and metabolic regulation [39, 40].

While our study provides valuable insights into the influence of sleep duration and quality on the prognosis of pancreatic cancer in the elderly, certain limitations must be acknowledged. First, the retrospective nature of the study may introduce selection bias, as it relies on historical data and patient records, possibly affecting the generalizability of the findings. Moreover, the use of a single type of wearable device limits the generalizability of our findings. Our study population was limited to a specific geographic region, which might not reflect broader populations, and the sample size, although adequate, was limited, possibly affecting the statistical power of some analyses. Lastly, while we identified associations between sleep variables and prognosis, the study design did not allow for causation determination, necessitating further prospective research to validate these findings and explore underlying mechanisms.

Conclusion

Sleep duration and quality were pivotal determinants of surgical and oncological outcomes in elderly pancreatic cancer patients. The use of wearable smart devices offers an innovative and effective tool for continuous and accurate sleep monitoring, contributing to a deeper understanding of the interaction between sleep and cancer prognosis. As these technologies become more integrated into routine clinical practice, they offer a unique opportunity to personalize recovery pathways by leveraging sleep metrics as actionable clinical indicators. This holistic approach not only aims to enhance life quality but also has the potential to improve long-term survival through better management of physiological and psychological stressors inherent to cancer care. Future research should focus on elucidating the specific biological mechanisms of these observations and evaluating targeted interventions to modify sleep dynamics.

Acknowledgements

This study was supported by Henan Provincial Department of education, Yujiao (2023j70282).

Disclosure of conflict of interest

None.

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