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A cross-sectional study on the association between physical activity and the risk of colon cancer based on NHANES 2007–2018

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Colon cancer poses a significant threat to global health, and studies have shown a correlation between physical activity (PA) and the incidence of colon cancer. However, existing research has not quantitatively analyzed PA to evaluate its impact on the risk of colon cancer comprehensively. Data related to the study were obtained from the NHANES database for participants aged 20 and above between 2007 and 2018. Calculate the daily total metabolic equivalent (MET) based on the duration of different physical activities for each participant, use multivariate logistic regression analysis to evaluate the association between PA and colon cancer risk, perform subgroup analysis to calculate adjusted odds ratios (ORs) and 95% confidence intervals (CIs) between different subgroups, and use RCS regression analysis to evaluate the non-linear relationship between MET and colon cancer risk. After adjusting for potential confounding factors, multivariate logistic regression analysis showed that compared with the overall data of the participants in this study, the OR of the low PA group (PA ≤ 120MET/day) was 1.224 (95% CI 1.031–1.453, *P* = 0.023), the OR of the mild PA group (120 < PA ≤ 600MET/day) was 1.026 (95%CI 0.707–1.488, *P* = 0.894), the OR of the moderate intensity PA group (600 < PA ≤ 1200MET/day) was 0.798 (95% CI 0.506–1.258, *P* = 0.334), and the OR of the high-intensity PA group (PA > 1200MET/day) was 0.470 (95% CI 0.249–0.885, *P* = 0.022), these results are consistent in subgroup analysis. The RCS regression analysis results showed a significant nonlinear relationship between MET and the risk of colon cancer(*p* < 0.001), with an inflection point observed at 1879 MET/day on the correlation curve. Low physical activity increases the risk of colon cancer, while moderate to high-intensity physical activity can reduce the risk of colon cancer. The results of this study emphasize the importance of maintaining appropriate physical activity as a healthy way to prevent colon cancer.

Colorectal cancer (CRC) is the most common malignant tumor of the digestive tract worldwide[1]. The latest epidemiological data shows that colorectal cancer ranks third in the incidence rate of cancer and second in the mortality rate in the United States[2]. Colon cancer is the most common pathological subtype of colorectal cancer, accounting for approximately 70% of all colorectal cancer pathologies[3]Serious threat to human life and health. Cancer is caused by complex etiologies, involving genetic, environmental, and lifestyle factors and their interactions. Therefore, preventing cancer through lifestyle changes is a feasible approach[4]. Many epidemiological studies have shown that active physical activity (PA) is beneficial to physical health, and people with PA higher than the recommended level are associated with lower incidence rates and mortality[5]. In oncology, many studies have shown a strong association between PA and cancer risk[6,7]. In the field of tumors, numerous studies have shown a strong correlation between PA and the risk of cancer, with research indicating that higher intensity PA is associated with a reduced risk of tumor onset in breast cancer[8], endometrial cancer[9], lung cancer[10], and colon cancer[11,12]. Studies have also explored the potential relationship between different types of physical activity and the risk of tumor onset, with findings suggesting that increasing occupational physical activity, recreational physical activity, and physical activity during walking may help prevent the occurrence of colorectal cancer[13]. However, systematic review and meta-analysis studies have shown that although physical activity is associated with a reduced risk of colon cancer, the difference does not reach statistical significance[14].

Although many studies have shown that PA is related to the incidence rate of colon cancer, the existing studies still have some limitations. First, many studies are systematic meta-analysis, which has the problem of

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sample heterogeneity between different studies. Secondly, current research shows that PA can reduce the risk of colon cancer, but it is well known that low physical activity is not conducive to physical health[15,16]. Low physical activity does not reduce the risk of colon cancer, but may increase the risk of colon cancer. Therefore, it is urgent to conduct a quantitative analysis of PA to comprehensively evaluate its impact on the risk of colon cancer. This study used the NHANES database to assess the association between PA levels and the risk of colon cancer in adults in the United States, to find the best level of physical activity to reduce the incidence rate of colon cancer, and to improve the understanding of the potential impact of lifestyle intervention on the incidence rate of colon cancer.

Materials and methods

Database

In this study, we utilized data from the National Health and Nutrition Examination Survey (NHANES) in the United States, a cross-sectional analysis using stratified, multi-stage probability sampling in a non-institutionalized population. Detailed demographic and health information was collected through interviews, physical examinations, and laboratory tests in mobile examination centers to assess non-institutionalized Americans' health and nutritional status. The National Center for Health Statistics (NCHS) is responsible for conducting this survey. Participation in NHANES requires filling out an informed consent form authorized by the NCHS Ethics Review Committee. Using existing NHANES data for this analysis does not require additional approval from the Institutional Review Board. In this study, we used the NHANES dataset from 2007 to 2018. The data for the NHANES project can be found on the NHANES website(https://www.cdc.gov/nchs/nhanes/index.htm).

Study population

This study recruited individuals who had completed interviews with NHANES data from 2007 to 2018, but excluded individuals with incomplete exposure variables, outcome variables, and covariates. To ensure the accuracy of cancer outcome variables, we used the questions in the medical condition questionnaire (Have you ever been told by a doctor or other health professional that you had cancer or a malignancy of any kind?). Participants who answered 'yes' further determined the tumor type based on the question' What kind of cancer was it? 'Participants who answered' colon 'were classified as colon cancer positive, while those who answered' no 'were classified as cancer negative. Participants who answered 'refuse' or 'I don't know' were excluded from the analysis.

Exposure variables

The PA report uses the Global Physical Activity Questionnaire (GPAQ) to provide data on the physical activity level of respondents. PA is divided into five types: high-intensity work, moderate-intensity work, walking/cycling traffic, intense recreational activities, and moderate recreational activities. Determine through the following 5 questions: (1) How much time do you usually spend on high-intensity activities at work every day? (2). How much time do you usually spend on moderate-intensity activities at work every day? (3). How much time do you usually spend walking or cycling for travel every day? (4). How much time do you usually spend on high-intensity exercise, fitness, or recreational activities every day? (5). How much time do you usually spend on moderate-intensity exercise, fitness, or recreational activities every day? Referring to the metabolic equivalent (MET) score recommended by NHANES, the MET score for high-intensity work and intense recreational activities is 8.0; The MET score for moderate-intensity work, walking/cycling traffic, and moderate recreational activities is 4.0. The MET of each activity is determined by multiplying its duration by the corresponding score. The total MET is calculated by adding the MET of each activity within a day.

Covariance

Based on previous literature, the potential impact of multiple covariates was evaluated. Covariates include age, race/ethnicity, education level, household income, smoking habits, alcohol consumption, and sedentary time. Race/ethnic categories include: non-Hispanic white, non-Hispanic black, Mexican American, and other races. The education level is divided into 5 groups: less than 9th grade, 9th–11th grade (including 12th grade without diploma), high school graduation/GED or equivalent, and college degree or above. Household income is evaluated based on the ratio of family income to poverty (PIR). According to previous research[17]We divided the participants into three groups: low-income (PIR ≤ 1), middle-income (1 < PIR < 4), and high-income (PIR ≥ 4). Smoking status is determined through the question (Have you smoked at least 100 cigarettes in your entire life?), where respondents who answer "yes" are defined as having a smoking history, while those who answer "no" are defined as having no smoking history. The drinking situation is determined by the question (Had at least 12 alcohol drinks/1 year?), where a respondent's answer of "yes" is defined as having a history of drinking, and a respondent's answer of "no" is defined as having no history of drinking. The duration of sedentary behavior was determined with the use of questions(How much time do you usually spend sitting on a typical day?). Many studies report that sedentary behavior (SB) time is divided into SB < 8 h/day and SB ≥ 8 h/day, which is the critical value associated with an increased risk of adverse clinical health outcomes for SB time[18,19]. Therefore, based on previous studies, we divided participants into SB ≤ 4 h, 4 h< SB<8 h, and SB ≥ 8 h according to their sedentary time.

Statistical analysis

The statistical analysis of the study considered sample weights and performed weighted calculations using the R language "survey" software package. According to the distribution characteristics, categorical variables are expressed as percentages (%), and continuous variables are expressed as means (SD). Use t-test and Wilcoxon

rank sum test to analyze the differences in continuous variables between the colon cancer group and non-tumor group. Use the chi-square test to analyze the categorical variables between two groups. Use multivariate logistic regression to investigate the association between PA and the incidence of colon cancer. The nonlinear relationship between PA and the incidence rate of colon cancer was further evaluated by using the RCS (Restricted cubic spline) regression analysis. Finally, we also conducted a covariate stratified subgroup analysis to assess the relationship between PA and the incidence rate of colon cancer in different subgroups.

As this study utilized the NHANES dataset, the sample size was predetermined by the survey design. As a secondary data analysis, we did not conduct preliminary statistical efficiency calculations, but focused on analyzing available data. All statistical analyses were conducted using the R 4.3.1 version. A p-value less than 0.05 is considered statistically significant.

Results

Inclusion and exclusion criteria for the study population

This study collected data from six survey cycles of NHANES from 2007 to 2018, with a total of 59,842 participants. Firstly, participants under the age of 20 were excluded, followed by those with missing covariates, exposure variables, and outcome variables. The detailed study population inclusion criteria are shown in Fig. 1, and ultimately 24,677 participants were included in the final analysis (Fig. 1).

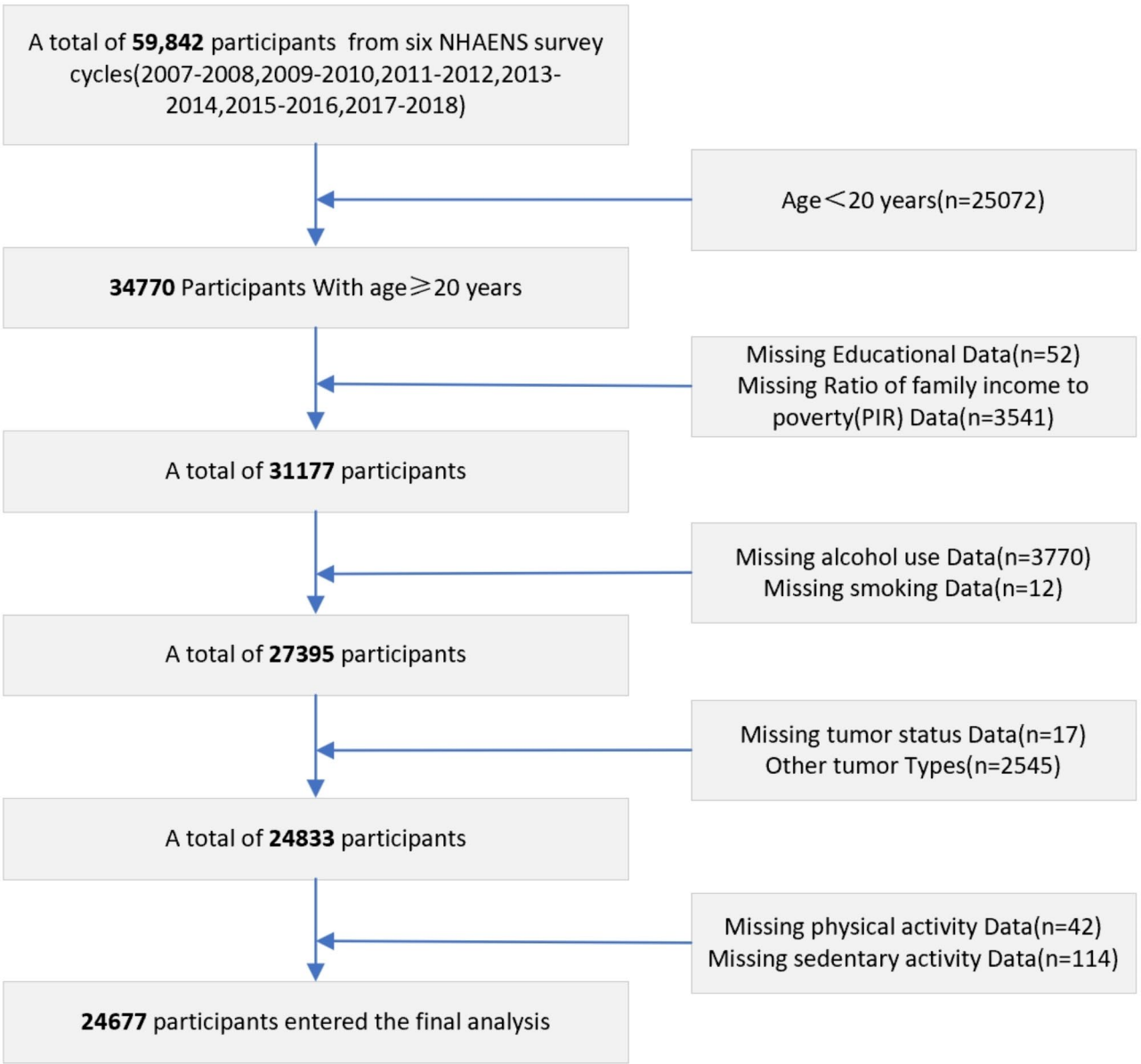

Fig. 1. Study population enrollment process.

Baseline characteristics

We calculated the MET of each participant based on the duration of different types of PA and their corresponding MET scores per day. Based on previous research, it is recommended to engage in moderate-intensity physical activity for at least 30 min or more per day[15,16]. We divided participants' PA levels into four groups based on MET: low PA (PA ≤ 120MET/day), mild PA (120 < PA ≤ 600MET/day), moderate intensity PA (600 < PA ≤ 1200MET/day), and high-intensity PA (PA > 1200MET/day).

Table 1 presents the baseline characteristics of all participants in detail (Table 1), with a gender ratio of 24,677 participants (male: female 12200:12477) and an average age of 48.20 ± 17.30 years. Among the participants, 180 were colon cancer patients, and 24,497 participants had no history of cancer. The average age of the 180 patients with colon cancer was 69.39 ± 11.93 years old. The incidence rate of men was slightly higher than that of women: 94 (52.2%) vs. 86 (47.8%). Table 1 also shows the relationship between exposure variables and covariates and the incidence rate of colon cancer. The results show that the incidence rate of colon cancer is significantly related to age, race, physical activity, and smoking (all $P < 0.001$).

Association between PA and the risk of colon cancer incidence

We used multivariate logistic regression to investigate the association between PA and the incidence of colon cancer. To correct the possible impact of confounding factors on the results, we constructed three models and gradually adjusted the covariates involved. In Model 1, we did not add covariates for adjustment. In Model 2, we added social demographic factors such as age, gender, race/ethnicity, education, and household income for adjustment. Model 3 includes a comprehensive set of adjustments: age, gender, race/ethnicity, education,

Characteristic	Level	Overall	Normal	Colon cancer	*p*
n		24,677	24,497	180	
Gender (%)					0.5
	Female	12,477 (50.6)	12,391 (50.6)	86 (47.8)	
	Male	12,200 (49.4)	12,106 (49.4)	94 (52.2)	
Age (mean (SD))		48.20 (17.30)	48.04 (17.23)	69.39 (11.93)	< 0.001
Race (%)					< 0.001
	Mexican American	3755 (15.2)	3745 (15.3)	10 (5.6)	
	Non-Hispanic Black	5379 (21.8)	5342 (21.8)	37 (20.6)	
	Non-Hispanic White	10,017 (40.6)	9904 (40.4)	113 (62.8)	
	Other Hispanic	2540 (10.3)	2529 (10.3)	11 (6.1)	
	Other Race - Including Multi-Racial	2986 (12.1)	2977 (12.2)	9 (5.0)	
Education (%)					0.226
	9-11th grade	3463 (14.0)	3434 (14.0)	29 (16.1)	
	College graduate or above	5747 (23.3)	5715 (23.3)	32 (17.8)	
	High school graduate	5702 (23.1)	5661 (23.1)	41 (22.8)	
	Less than 9th grade	2355 (9.5)	2331 (9.5)	24 (13.3)	
	Some college or AA degree	7410 (30.0)	7356 (30.0)	54 (30.0)	
PIR (%)					0.16
	PIR ≤ 1	5495 (22.3)	5461 (22.3)	34 (18.9)	
	1< PIR < 4	13,054 (52.9)	12,946 (52.8)	108 (60.0)	
	PIR ≥ 4	6128 (24.8)	6090 (24.9)	38 (21.1)	
Alcohol (%)					0.157
	No	6210 (25.2)	6156 (25.1)	54 (30.0)	
	Yes	18,467 (74.8)	18,341 (74.9)	126 (70.0)	
Physical activity PA (%)					< 0.001
	PA ≤ 120(MET/d)	9029 (36.6)	8924 (36.4)	105 (58.3)	
	120< PA ≤ 600(MET/d)	6218 (25.2)	6176 (25.2)	42 (23.3)	
	600< PA ≤ 1200(MET/d)	3800 (15.4)	3784 (15.4)	16 (8.9)	
	PA>1200 (MET/d)	5630 (22.8)	5613 (22.9)	17 (9.4)	
Sedentary behaviour SB(%)					0.08
	SB ≤ 4 h	10,204 (41.4)	10,143 (41.4)	61 (33.9)	
	4 h< SB<8 h	6346 (25.7)	6289 (25.7)	57 (31.7)	
	SB ≥ 8 h	8127 (32.9)	8065 (32.9)	62 (34.4)	
Smoke (%)					0.001
	No	13,838 (56.1)	13,759 (56.2)	79 (43.9)	
	Yes	10,839 (43.9)	10,738 (43.8)	101 (56.1)	

Table 1. Baseline characteristics of participants.

household income, sedentary time, smoking history, and drinking history. These adjustments corrected the potential impact of confounding factors on the results, further enhancing the reliability of the findings in this study.

After adjusting for potential confounding factors, the model demonstrated a negative correlation between PA levels and the risk of colon cancer. In the fully adjusted Model 3, compared with the overall data of the participants in this study, the OR of the low PA group was 1.224 (95% CI 1.031–1.453, $P=0.023$), the OR of the mild PA group was 1.026 (95% CI 0.707–1.488, $P=0.894$), the OR of the moderate intensity PA group was 0.798 (95% CI 0.506–1.258, $P=0.334$), and the OR of the high-intensity PA group was 0.470 (95% CI 0.249–0.885, $P=0.022$) (Fig. 2). After adjusting for all covariates, we found that the risk of colon cancer in the low PA group significantly increased by 22.4%. As physical activity increases, the risk of colon cancer gradually decreases. There was no significant difference in the risk of colon cancer in the mild PA group compared to the overall sample. The risk of colon cancer in the moderate-intensity PA group was significantly reduced by 20.2%, and in the high-intensity PA group, the risk of colon cancer was significantly reduced by 53.0%. To further evaluate the association between PA and the risk of colon cancer, we used RCS regression analysis to assess the relationship between MET and the risk of colon cancer. As shown in Fig. 3, there is a significant causal relationship (P-overall:<0.001) and a significant non-linear relationship (P-non-linear:<0.001) between MET and the risk of colon cancer. The result shows that as MET increases, the risk of colon cancer gradually decreases. However, at 1879 MET/day, the correlation curve shows a turning point, indicating that increasing physical activity within a certain range can reduce the risk of colon cancer (Fig. 3).

Subgroup analysis of the association between PA and the risk of colon cancer incidence

We conducted subgroup analyses for four different PA levels to evaluate the impact of physical activity on the risk of colon cancer across subgroups (Figs. 4, 5, 6, 7). Subsequently, interaction effect analysis was used to assess whether participant characteristics affected the association between physical activity (PA) and the risk of colon cancer. The results showed a significant interaction in the sedentary time subgroup ($p=0.043$) (Figs. 4, 5, 6, 7). Although there was an interactive effect in the sedentary time subgroup, the risk of colon cancer incidence increased in all subgroups in the low PA group (Fig. 4). It decreased in all subgroups in the high-intensity PA group (Fig. 7). This once again indicates a stable association between PA and the risk of colon cancer.

Discussion

This cross-sectional study assessed the association between PA and the incidence rate of colon cancer in adults in the United States. The results showed that PA was significantly related to the incidence rate of colon cancer, and the risk of colon cancer decreased with the increase of PA intensity. Compared with all participants included in the study, the risk of colon cancer in the low PA group ($P\leq 120$MET/day) was significantly increased by 22.4% (95% CI 1.031–1.453, $P=0.023$), the mild PA group (120< PA ≤ 600MET/day) had no significant impact on the incidence rate of colon cancer OR 1.026 (95% CI 0.707–1.488, $P=0.894$), the risk of colon cancer in the moderate PA group (600< PA ≤ 1200MET/day) was reduced by 20.2% (95% CI 0.506–1.258, $P=0.334$), and the

Variable	Group	OR (95% CI)	pvalue
model1	MET<=120	1.79610 (1.50059 to 2.14981)	<0.001
	120<MET<=600	0.97927 (0.67042 to 1.43041)	0.914
	600<MET<=1200	0.62227 (0.39757 to 0.97396)	0.041
	MET>1200	0.28754 (0.14321 to 0.57731)	<0.001
model2	MET<=120	1.23224 (1.01316 to 1.49870)	0.040
	120<MET<=600	1.03048 (0.70479 to 1.50669)	0.877
	600<MET<=1200	0.79175 (0.49598 to 1.26390)	0.331
	MET>1200	0.45990 (0.23732 to 0.89125)	0.024
model3	MET<=120	1.22408 (1.03140 to 1.45275)	0.023
	120<MET<=600	1.02569 (0.70702 to 1.48800)	0.894
	600<MET<=1200	0.79765 (0.50574 to 1.25805)	0.334
	MET>1200	0.46973 (0.24934 to 0.88493)	0.022

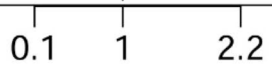

Fig. 2. Multivariable logistic regression analyses of physical activity and risk of colon cancer incidence. Model 1: Non-adjusted. Model 2: adjusted for age, gender, race/ethnicity, education, and household income. Model 3: adjusted for age, gender, race/ethnicity, education, household income, sedentary time, smoking history, and drinking history.

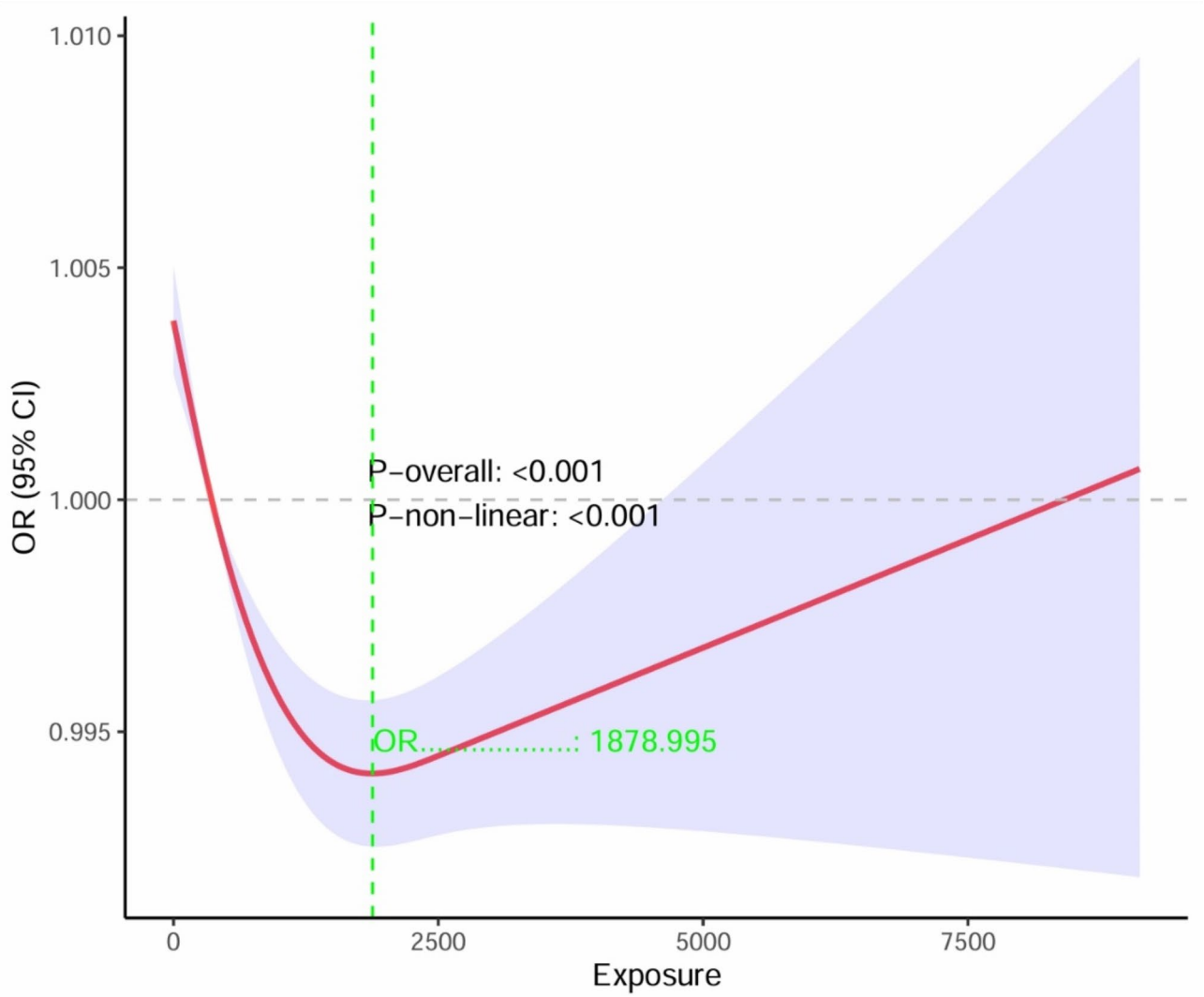

Fig. 3. RCS regression analysis the relationship between MET and the risk of colon cancer. Significant causal relationship (P-overall:<0.001) and a significant non-linear relationship (P-non-linear:<0.001) between MET and the risk of colon cancer. At 1879 MET/day, the correlation curve shows a turning point.

risk of colon cancer in the high-intensity PA group (PA>1200MET/day) was reduced by 53.0% (95% CI 0.249–0.885, $P=0.022$). The results showed that low physical activity increased the risk of colon cancer and was indeed an unhealthy lifestyle, which was consistent with previous studies[15,16]. Meanwhile, research has also shown that high-intensity physical activity can reduce the risk of colon cancer, consistent with previous studies[12,13]. This emphasizes that a reasonable and healthy lifestyle is particularly important for preventing the occurrence of colon cancer.

In the past, many studies have explored the relationship between the incidence rate of colorectal cancer and PA. One study assessed the relationship between PA and the risk of colorectal cancer in Asian people. This study recruited 63,257 adults in total. The results showed that compared with those without physical activity, any intense physical activity in men was significantly associated with a statistically significant reduction in the risk of colorectal cancer (HR = 0.84,95% CI 0.71–0.99), while there was no significant statistical significance in female participants[12]. A systematic meta-analysis of 17 cohort studies and 21 case-control studies involving approximately 3.5 million participants showed that different types of physical activity can reduce the risk of colon cancer to some extent[13]. However, previous studies have not quantitatively analyzed different physical activities. In this study, we systematically integrated different physical activities and converted each participant's physical activity level into MET based on the recommended MET score by NHANES. Subsequently, participants were divided into four PA levels based on their MET scores. The results indicate that the risk of colon cancer is significantly increased in the low PA group (PA ≤ 120MET/day), while the risk of colon cancer is significantly reduced in the high-intensity PA group (PA > 1200MET/day). Subsequent RCS regression analysis shows a significant nonlinear relationship between MET and the risk of colon cancer. As MET increases, the risk of colon cancer gradually decreases, and the curve reaches a turning point when MET is approximately 1879MET. The results of this study once again emphasize the association between PA and the risk of colon cancer, and also

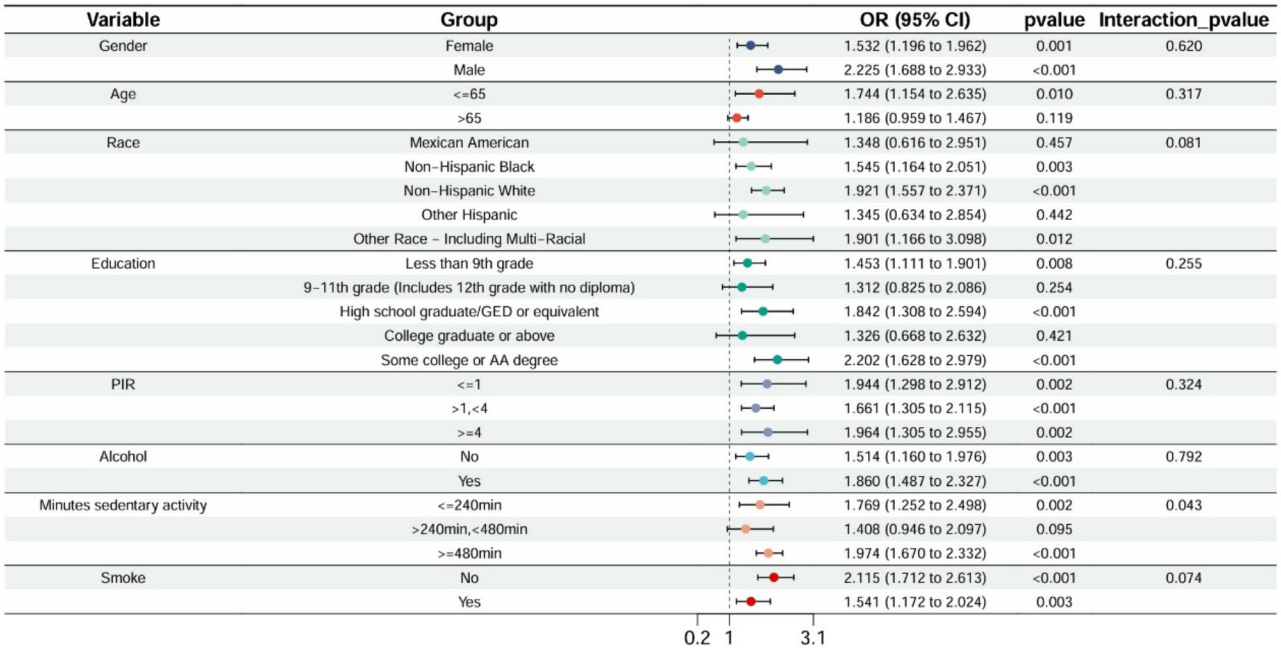

Fig. 4. Forest plots for subgroup analysis of the low PA group(PA ≤ 120MET/day).

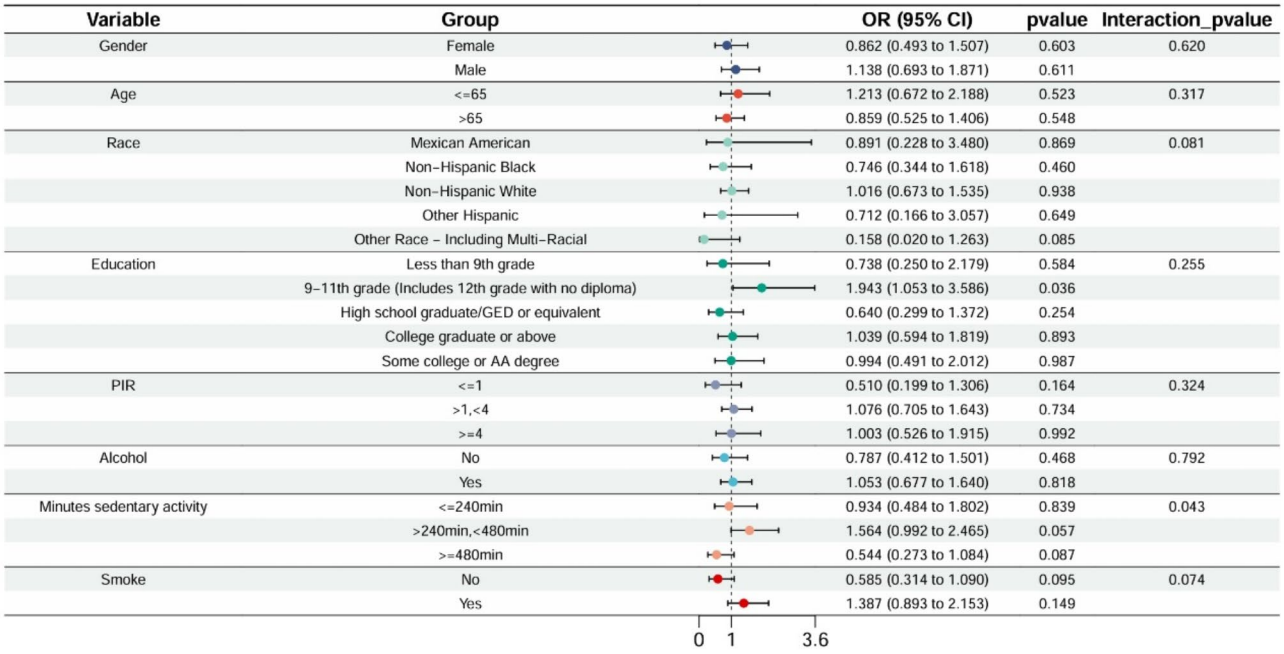

Fig. 5. Forest plots for subgroup analysis of the mild PA group(120< PA ≤ 600MET/day).

clarify the optimal amount of physical activity to reduce the risk of colon cancer. Our study results suggest that for individuals engaged in non-manual work, increasing high-intensity recreational activities (such as running or playing basketball) by about one hour per day or moderate-intensity recreational activities (such as brisk walking or cycling) by about two hours can significantly reduce the risk of colon cancer.

Many studies have shown that sedentary behavior can increase the risk of colon cancer[12,20]. To further enhance the stability of the results, we added covariates such as sedentary behavior time, smoking, alcohol consumption, household income, education level, and race during the study. Although there is a significant interaction between sedentary behavior subgroups, this is consistent with previous studies. However, subsequent subgroup analysis showed that the risk of colon cancer increased in all subgroups of the low PA group, while the risk of colon cancer decreased in all subgroups of the high-intensity PA group, once again highlighting the

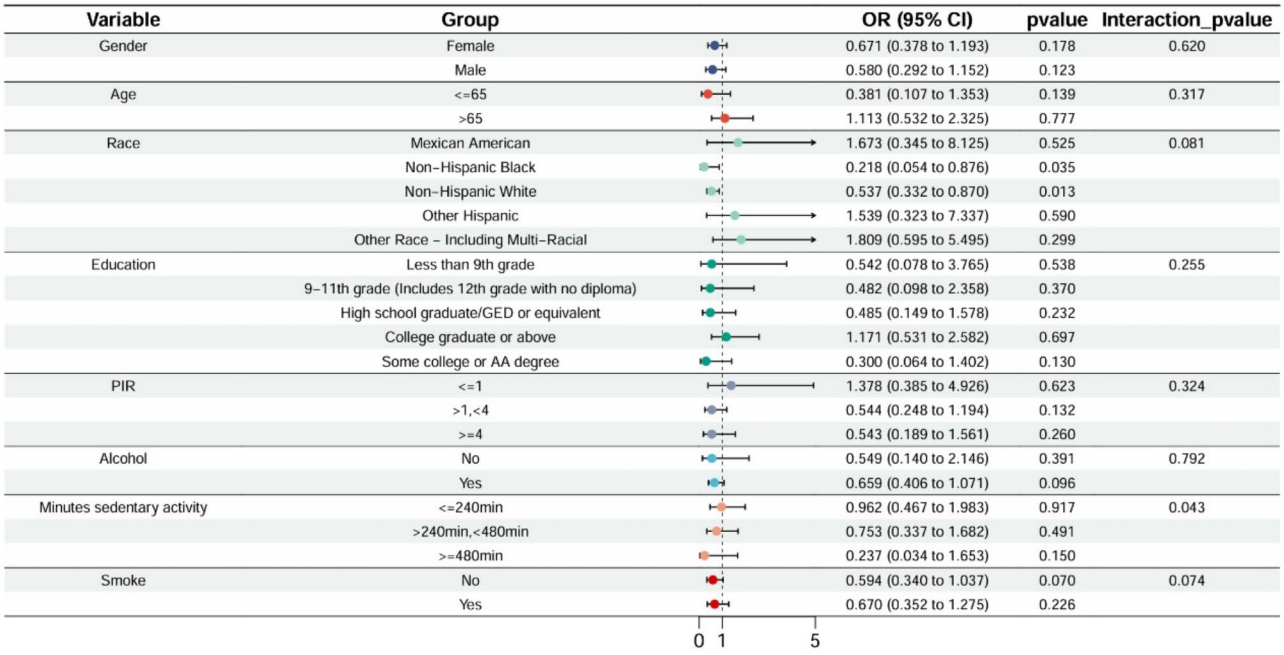

Fig. 6. Forest plots for subgroup analysis of the moderate intensity PA group(600 < PA ≤ 1200MET/day).

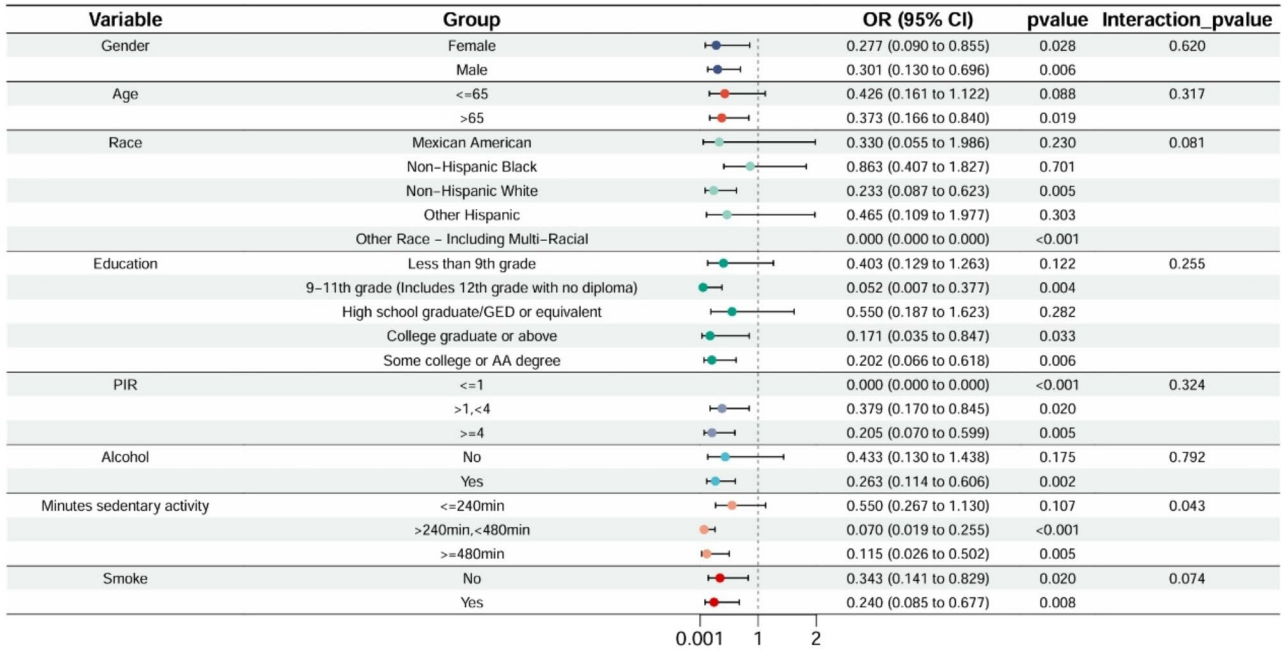

Fig. 7. Forest plots for subgroup analysis of the high-intensity PA group(PA>1200MET/day).

reliability of the results of this study. Previous studies have shown that sedentary behavior is associated with an increased risk of colon cancer. Our study results also indicate that low physical activity (PA) is associated with an increased risk of colon cancer. The combined effect of these two factors leads to a significant increase in the risk of colon cancer, resulting in a significantly higher risk of colon cancer in the low PA group with high sedentary time compared to the group with low sedentary time. Conversely, in the high-intensity PA group, high levels of PA can mitigate the impact of sedentary behavior on the risk of colon cancer, thus the reduction in colon cancer risk in the high sedentary time group is significantly greater than that in the low sedentary time group. This result suggests that high-intensity physical activity is particularly important for adults who with more sedentary behavior.

Many studies have explored the potential molecular mechanisms of exercise and tumor occurrence and development[21,22]. Basic research shows that exercise can alter the structure of colon crypt cells and inhibit their proliferation[23]. Some studies have also found that exercise can increase markers of cell apoptosis in colorectal tissue[24]. This may be a potential molecular mechanism by which PA reduces the risk of colon cancer. In a mouse model of colon cancer, compared with sedentary animals, exercising 6 days a week for 12 weeks on a treadmill for 1 h significantly reduced the number of large polyps ($P<0.05$), tumor-associated macrophages related to colon tumor progression were reduced in the exercise group compared to the sedentary group ($P<0.05$)[25]. The correlation between gut microbiota and the risk of colon cancer has been confirmed by many studies[26]. Exercise can promote gastrointestinal tract peristalsis, thus reducing the stimulation of harmful substances in feces on the colon, which may also be one of the possible reasons that exercise can reduce the incidence rate of colon cancer.

However, there are also some limitations to this study. Firstly, the data in this study was sourced from the NHANES database, although the National Center for Health Statistics (NCHS) in the United States has strict quality control and professional personnel responsible for conducting questionnaire surveys. The survey results rely on self-reporting, which may lead to participant recall bias. Secondly, after collecting participants from NHANES from 2007 to 2018, some participants had incomplete data, so these incomplete participants were deleted, which may lead to potential data deletion bias. Finally, as this study utilized public datasets, the sample size was predetermined by the survey design, resulting in fewer colon cancer patients among the participants, which may lead to a decrease in statistical power.

Conclusion

In summary, our research suggests that low physical activity is an unhealthy lifestyle that significantly increases the risk of colon cancer. In contrast, sufficient intensity of physical activity can significantly reduce the risk of colon cancer. This indicates that daily adherence to reasonable physical activity is particularly important for preventing colon cancer. At the same time, our study also highlights the association between sedentary behavior and the risk of colon cancer, and for individuals with prolonged sedentary behavior, special attention should be given to increasing physical activity.

Data availability

The data that support the findings of this study are openly available in the NHANES database: https://www.cdc.gov/nchs/nhanes/index.htm.

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Author contributions
Daoyang Zou was responsible for the data analysis, data reduction, and manuscript writing of this study; Xi Xin was responsible for software support and reviewing the manuscript; Yunxian Xu was responsible for investigating and reviewing the manuscript; Huangzhen Xu was responsible for investigating and reviewing the manuscript; Tianwen Xu was responsible for obtaining funding support, designing the project idea, and reviewing the final article.

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Declarations

Competing interests
The authors declare no competing interests.

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