Original Article Clinics in Orthopedic Surgery 2023;15:488-498 • https://doi.org/10.4055/cios22238

The Association of Body Mass Index and Waist Circumference with the Risk of Achilles Tendon Problems: A Nationwide Population-Based Longitudinal Cohort Study

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Background: The purpose of this study was to evaluate the association of body mass index (BMI) and waist circumference (WC) with the risk of Achilles tendinopathy (AT) or Achilles tendon rupture (ATR), using data from a nationwide population-based cohort. We hypothesized that higher BMI and WC would be independently associated with the increased risk of AT or ATR. In addition, a higher WC may potentiate the association between BMI and the risk of Achilles tendon problems.

Methods: We used the National Health Insurance database that covers the entire South Korean population to follow up subjects who participated in the National Health Screening Program (NHSP) from January 2009 to December 2010. The NHSP data include subjects' BMI, WC, blood test results, blood pressure, and information about lifestyle. Among the subjects, those who were newly diagnosed as having AT or ATR before December 31, 2017, were selected. To examine the association of the variables with the risk of AT or ATR and determine whether the effect of higher BMI varied according to WC, multivariate Cox proportional hazards regression was used.

Results: Among a total of 16,830,532 subjects, 125,814 and 31,424 developed AT and ATR, respectively. A higher BMI showed a greater association with the increased risk of ATR than AT (adjusted hazard ratio [HR], 3.49 vs. 1.96). A higher WC was associated with the increased risk of AT (adjusted HR, 1.22), but not ATR. In a separate analysis, the association between BMI and the risk of AT was higher when subjects had higher WC as compared to those with lower WC, being most significant in individuals with both higher BMI and higher WC.

Conclusions: Higher BMI was more associated with the increased risk of ATR than AT. Moreover, a high central fat distribution played an independent and potentiating role in the development of AT. This implies the greater importance of a high central fat distribution contributing to the development of AT in obese people.

Keywords: *Achilles tendinopathy, Achilles tendon rupture, Obesity, Body mass index, Waist circumference*

Achilles tendinopathy (AT), previously known as Achilles tendinitis, and Achilles tendon rupture (ATR) are two of the most common problems related to the Achilles tendon. Several factors, both intrinsic (age, sex, leg-length discrepancy, lower extremity malalignment, or decreased laxity) and extrinsic (therapeutic agents,[1,2] errors in training techniques, or high physical activity), are known to

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Received July 20, 2022; Revised December 2, 2022;
Accepted December 2, 2022

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influence the development of AT and ATR.[3,4] Particularly, there is increasing evidence that suggests obesity is a risk factor for the development of AT and ATR.

In the past, some studies indicated a positive association between AT, ATR, and body mass index (BMI),[5-12] while others reported negative[13-20] or no such relation.[21] As higher BMI may induce the increased absolute tendon load, resulting in low-grade inflammation,[22] several previous studies sought to establish a relationship between individual's current BMI and AT or ATR, but reported conflicting results.

Recently, it has been argued that waist circumference (WC) is a more predictable obesity-related risk factor than BMI.[23,24] WC can be a surrogate marker of abdominal adiposity (visceral fat and/or subcutaneous abdominal adipose tissue), while BMI does not represent the pattern of fat distribution. It has been hypothesized that a high central fat distribution may be a more accurate independent risk factor than higher BMI.[25] However, to date, the role of the high central fat distribution with respect to Achilles tendon problems has not been fully evaluated. Moreover, the effect of central fat distribution on higher BMI has yet to be investigated in association with the risk of AT or ATR.

As obesity is linked to other systematic conditions such as dyslipidemia,[26] hypertension, or glucose intolerance, which can independently influence the development of AT or ATR, control of these obesity-related confounding factors is important. Furthermore, no studies have calculated the incidence of AT or ATR according to BMI categories to date. Lastly, whether the effects of higher BMI vary by age, sex, or physical activity is still questionable because of the lack of studies on this issue.

Hence, we designed a study using data from the National Health Insurance (NHI) database of the adult population to evaluate the association of BMI and WC with the risk of AT or ATR. We hypothesized that higher BMI and WC can be independently associated with the risk of AT or ATR. In addition, a higher WC may potentiate the association between BMI and the risk of Achilles tendon problems.

METHODS

Ethical Review Committee Statement

This study was performed in accordance with the Declaration of Helsinki. The study was approved by the Inje University Ilsan Paik Hospital Institutional Review Board (No. 2019-05-021). Written informed consent was waived as the research presented no more than minimal risk of harm to participants and involved no procedures for which written consent was normally required of the research context.

Data Source, Database Information, and Identification of the Study Population

This nationwide population-based cohort study was based in South Korea, using its NHI claims database. The South Korean NHI system covers > 97% of the entire South Korean population (≥ 50 million) and includes all forms of medical services performed in the country. The NHI database contains the sociodemographic information of the beneficiaries, diagnosis based on the International Classification of Disease Tenth Revision (ICD-10) codes, all inpatient and outpatient claims data, primary and secondary diagnosis codes and treatment, and National Health Screening Program (NHSP) data.

The South Korean NHSP is a population-based health screening program provided by the South Korean NHI Corporation. All insured subjects are eligible to participate in the NHSP; this program recommends all participants undergo a standardized medical examination every 1 or 2 years. The NHSP data include subjects' medical interviews, postural examinations, body measurements (height, weight, and WC), chest X-ray examinations, systolic and diastolic blood pressures, regular blood/urine test results, and responses to questionnaires on lifestyle or medical histories, including smoking (pack-years) and alcohol consumption per week. Blood samples for the measurements of blood glucose and lipid levels were drawn after overnight fasting (at least 8 hours).

The database for this study was established by linking the NHSP data to the NHI claims database and contains the subjects' age, sex, diagnosis based on ICD-10 codes with the date of diagnosis, date of NHSP participation, height, weight, WC, low-density lipoprotein (LDL) cholesterol, triglyceride, high-density lipoprotein (HDL) cholesterol, fasting blood glucose levels, and systolic blood pressures. BMI was calculated as the subjects' weight (in kilograms) divided by the height (in meters squared). Information from the questionnaire regarding the frequency of high-intensity exercise per week was included. High-intensity exercise means breathtaking exercise such as sprinting or cycling.

From the database, we selected subjects who underwent the NHSP standardized medical examination from January 1, 2009, to December 31, 2010 (17,350,675 subjects). The exclusion criteria were age < 20 years at the time of medical examination and previous AT or ATR before the medical examination.

Grouping of BMI and WC and Categorization of Other Variables

As subjects with BMI > 30 kg/m^2 were uncommon in South Korea, the selected subjects were grouped according to BMI (kg/m^2) as follows: underweight (< 18.5), normal (18.5 to < 23), overweight (23 to < 25), and obese (≥ 25).[26,27] For the WC grouping, the subjects were divided into three groups according to the proportion of subjects with the corresponding WCs to the entire population: lower third, middle third, and upper third.

In addition to BMI and WC, we included age (20–39, 40–59, 60–79, and ≥ 80 years), sex, frequency of high-intensity exercise (none, infrequent [once or twice per week], and frequent [≥ 3 times/wk]), LDL cholesterol (< 130, ≥ 130 & < 160, and ≥ 160 mg/dL), triglyceride (< 150, ≥ 150 & < 200, and ≥ 200 mg/dL), HDL cholesterol (< 35, ≥ 35 & < 55, and ≥ 55 mg/dL for women; < 45, ≥ 45 & < 65, and ≥ 65 mg/dL for men), fasting blood glucose level (< 100, ≥ 100 & < 126, and ≥ 126 mg/dL), and systolic blood pressure (< 120, ≥ 120 & < 130, ≥ 130 & < 140, and ≥ 140 mm Hg) as covariables.

Study Outcomes and Verification of the Diagnosis

Based on the algorithm provided below, the primary outcome of this study was to identify subjects with three or more outpatient clinic visits for a newly diagnosed AT (ICD-10 code M76.6) or ATR (ICD-10 code S86.0).[28-30]

To verify the diagnostic accuracy, we developed several algorithms based on the number of healthcare visits of patients with AT or ATR. From the selected hospital, we reviewed the outpatient medical records of 200 randomly selected subjects who visited the orthopedic surgery outpatient clinic at least once with the AT or ATR code from January 2009 to January 2019. Two experienced orthopedic surgeons (JYC and JSS) independently reviewed the medical records to confirm the diagnosis. Then, we also retrieved 200 suspected non-Achilles tendon subjects (ICD-10 code M72.2 plantar fasciitis) to identify any potential misclassification bias. The sensitivity and specificity, as well as positive and negative predictive values of each algorithm, were calculated according to the number of outpatient clinic visits per year (Supplementary Table 1). Sensitivity and specificity for AT were 90.6% and 90.8%, respectively, and those for ATR were 90.7% and 94.9%, respectively, based on the algorithm selected, which reflected three or more visitations for AT or ATR.

Statistical Analyses

The subjects in the whole study population, according to the BMI and WC groups, were followed up since the date

Table 1. Baseline Characteristics of Study Population (N = 16,830,532)

Parameter	No. (%)
Age (yr)	
20–39	4,726,275 (28.08)
40–59	8,113,861 (48.21)
60–79	3,779,653 (22.46)
≥ 80	210,743 (1.25)
Sex	
Female	8,153,227 (48.44)
Male	8,677,305 (51.56)
Body mass index (kg/m^2)	
Underweight (< 18.5)	632,214 (3.76)
Normal (≥ 18. 5 & < 23)	6,580,463 (39.10)
Overweight (≥ 23 & < 25)	4,126,563 (24.52)
Obese (≥ 25)	5,484,927 (32.59)
Frequency of high-intensity exercise per week	
None	10,412,654 (61.87)
Infrequent (≤ 2)	3,762,159 (22.35)
Frequent (≥ 3)	2,495,775 (14.83)
Waist circumference	
Lower third	5,922,388 (35.19)
Middle third	6,380,330 (37.91)
Upper third	4,520,597 (26.86)
LDL cholesterol (mg/dL)	
< 130	11,774,208 (69.96)
≥ 130 & < 160	3,437,893 (20.43)
≥ 160	1,553,137 (9.23)
Triglyceride (mg/dL)	
< 150	11,908,448 (70.76)
≥ 150 & < 200	2,305,337 (13.70)
≥ 200	2,616,272 (15.54)
HDL cholesterol (mg/dL)	
< 35 (women), < 45 (men)	2,046,311 (12.16)
≥ 35 & < 55 (women), ≥ 45 & < 65 (men)	11,761,522 (69.88)
≥ 55 (women), ≥ 65 (men)	3,021,200 (17.95)

Table 1. Continued

Parameter	No. (%)
Fasting blood glucose (mg/dL)	
< 100	11,616,853 (69.02)
≥ 100 & < 126	4,133,861 (24.56)
≥ 126	1,079,677 (6.41)
Systolic blood pressure (mm Hg)	
< 120	6,762,637 (40.18)
≥ 120 & < 130	4,164,222 (24.74)
≥ 130 & < 140	3,842,396 (22.83)
≥ 140	2,058,340 (12.23)

LDL: low-density lipoprotein, HDL: high-density lipoprotein.

of the first medical examination through the NHSP until a newly diagnosed AT, ATR, or death by December 31, 2017. Subjects diagnosed as having both were grouped according to their first initial diagnosis.

The baseline characteristics of all the subjects and BMI groups were evaluated. To examine the association of the variables with the risk of AT or ATR, multivariate Cox proportional hazards regression was used, and hazard ratios (HRs) were computed with 95% confidence intervals (CIs). The independent variables were age, sex, BMI, WC, frequency of high-intensity exercise, LDL cholesterol, triglyceride, HDL cholesterol, fasting blood glucose level, and systolic blood pressure, while the dependent variables were the development of AT and ATR. The proportional hazards assumptions were verified using Schoenfeld residuals.

We then calculated the incidence rates (IR) of AT and ATR for all the subjects and BMI and WC groups. The IR was defined as the number of new AT or ATR cases per 10,000 person-years. The person-year was calculated for each subject from the date of NHSP medical examination to the respective date of diagnosis. Incidence curves were also used to estimate the cumulative IR in the BMI and WC groups. Furthermore, we calculated the multivariable-adjusted HR of WC for each BMI group to determine whether the association between BMI and the risk of Achilles tendon problems varied according to WC.

To determine whether the association of higher BMI with the risk of AT or ATR varied by age, sex, or physical activity level, we stratified our analysis by subgroup using multivariate Cox regression based on age, sex, or frequency of high-intensity exercise per week. All the statistical

Table 2. Incidence Rates per 10,000 PYs and Adjusted HR of Achilles Tendinopathy and Tendon Rupture for Each BMI Group

	Underweight (BMI < 18.5 kg/m^2)			Normal (18.5 ≤ BMI < 23 kg/m^2)			Overweight (23 ≤ BMI < 25 kg/m^2)			Obese (BMI ≥ 25 kg/m^2)		
	Events/ total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)	Events/ total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)	Events/ total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)	Events/ total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)
Achilles tendinopathy	2,643/ 4,834,015	5.47 (5.26–5.68)	Reference	39,807/ 51,281,740	7.76 (7.69–7.84)	1.34 (1.29–1.39)	31,219/ 32,249,335	9.68 (9.57–9.79)	1.61 (1.55–1.68)	52,093/ 42,798,002	12.17 (12.07–12.28)	1.96 (1.88–2.05)
Achilles tendon rupture	369/ 4,824,693	0.76 (0.69–0.85)	Reference	8,258/ 51,153,518	1.61 (1.58–1.65)	1.83 (1.65–2.03)	8,118/ 32,155,155	2.52 (2.47–2.58)	2.59 (2.33–2.89)	14,660/ 42,644,418	3.44 (3.38–3.49)	3.49 (3.13–3.90)

PY: person-year, HR: hazard ratio, BMI: body mass index, IR: incidence rate, CI: confidence interval.

tests were two-sided, and *p*-values < 0.05 were considered statistically significant. STATA 15.0 (StataCorp.) was used in all the statistical analyses.

RESULTS

Characteristics of the Study Population and IRs of AT and ATR

The study population included 16,830,532 subjects after applying the exclusion criteria (Table 1). Subjects aged between 40 and 59 years were most frequent (48.21%). Women accounted for 48.44% of the subjects. Regarding BMI of the subjects, 3.76% were underweight, 39.10% were normal, 24.52% were overweight, and 32.59% were obese. Baseline characteristics according to the BMI groups are summarized in Supplementary Table 2. Among the study population, 125,814 and 31,424 subjects developed AT and ATR, with corresponding IR of 9.59 and 2.40 per 10,000 person-years.

Association of BMI or WC and the Risk of AT or ATR

Compared with the underweight group (Table 2), the obese and overweight groups showed 2.2 and 1.8 times higher IR of AT, respectively. The IR of the normal group was 1.4 times that of the underweight group. We observed a similar trend for ATR, but with a greater magnitude. The IR was 4.5 times higher in the obese group and 3.3 times higher in the overweight group than in the underweight group. The IR of the normal group was 2.1 times that of the underweight group.

The incidence curves show that cumulative IRs of AT and ATR steadily increased over time as BMI increased (Fig. 1A). Multivariate Cox proportional hazards regression revealed that higher BMI was significantly associated with the increased risk of both AT and ATR, but with greater magnitude for ATR (adjusted HR, 3.49; 95% CI, 3.13–3.90 vs. adjusted HR, 1.96; 95% CI, 1.88–2.05).

According to WC, the IR was highest in the upper third group for both AT and ATR (Table 3). The cumulative IRs of AT and ATR also increased over time with increased WC (Fig. 1B). Multivariate Cox proportional hazards regression revealed that higher WC was associated with the increased risk of AT (adjusted HR, 1.22; 95% CI, 1.19–1.24), though with a smaller magnitude compared to

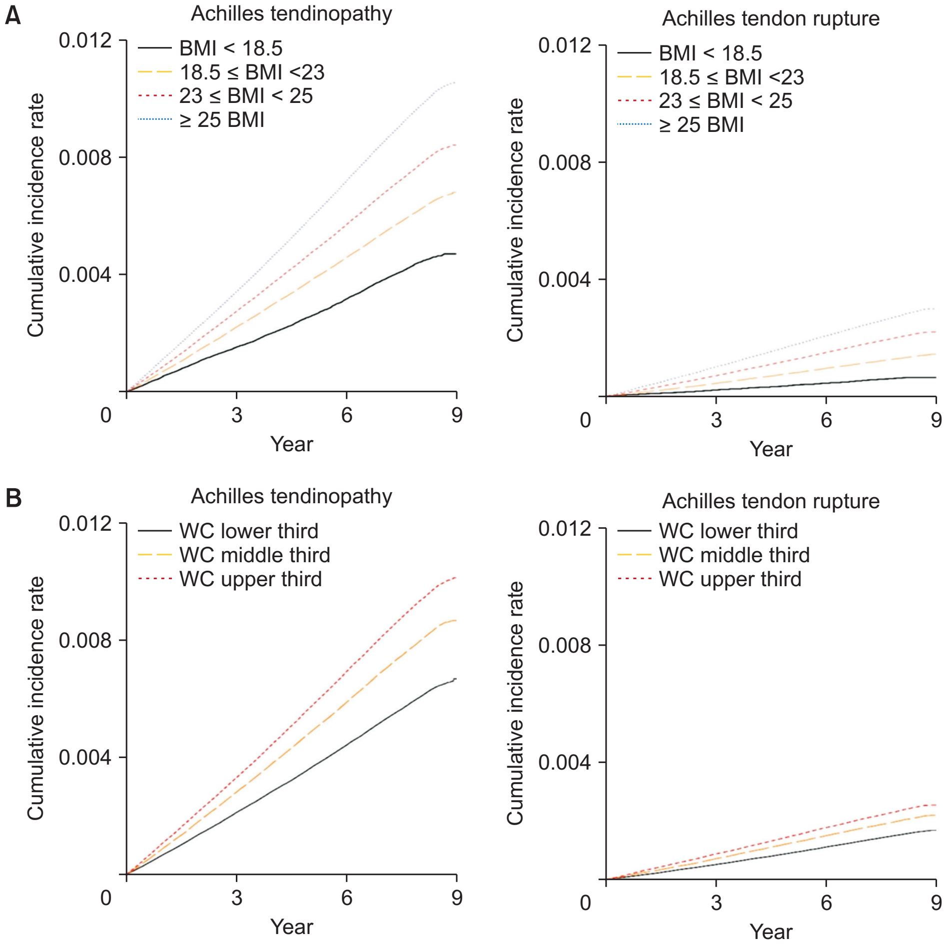

Fig. 1. Incidence curves of Achilles tendinopathy and tendon rupture according to body mass index (BMI; kg/m^2, A) and waist circumference (WC; B). The incidence rates of Achilles tendinopathy or tendon rupture increased steadily over time with increased BMI or WC.

Table 3. Incidence Rates per 10,000 PYs and Adjusted HR of Achilles Tendinopathy and Tendon Rupture for Each WC Group

	Lower third			Middle third			Upper third		
	Events/total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)	Events/total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)	Events/total PYs	IR per 10,000 PYs (95% CI)	Adjusted HR (95% CI)
Achilles tendinopathy	35,059/59,321,489	5.91 (5.62–6.24)	Reference	49,741/64,181,935	7.75 (7.58–8.02)	1.11 (1.10–1.13)	40,977/44,930,921	9.12 (8.82–9.42)	1.22 (1.19–1.24)
Achilles tendon rupture	8,765/59,222,972	1.48 (1.23–1.73)	Reference	12,408/64,625,002	1.92 (1.68–2.16)	1.02 (0.99–1.06)	10,237/44,703,056	2.29 (2.15–2.43)	1.05 (1.00–1.09)

PY: person-year, HR: hazard ratio, WC: waist circumference, IR: incidence rate, CI: confidence interval.

BMI. For ATR, higher WC was not significantly associated with the increased risk (adjusted HR, 1.05; 95% CI, 1.00–1.09). The cumulative adjusted HRs for whole variables regarding AT and ATR are shown in Fig. 2.

Effect of WC on the Association of BMI and the Risk of AT or ATR

For each BMI group, we observed the association was higher when subjects had higher WC as compared to those with lower WC, being most significant in individuals with both higher BMI and higher WC (Fig. 3). In the obese group (BMI ≥ 25 kg/m^2), higher WC was associated with the increased risk of AT by 30% compared with lower WC (adjusted HR, 1.30; 95% CI, 1.24–1.37). In the overweight and normal BMI groups, the adjusted HR of the upper third group compared with the lower third group was 1.08 (1.04–1.12) and 1.10 (1.04–1.16), respectively.

Association of BMI and the Risk of AT or ATR According to Age, Sex, and High-Intensity Exercise

By subgroup analysis (Table 4), we found that a higher BMI (≥ 25 kg/m^2) was similarly associated with the increased risk of AT in all age groups except for those aged ≥ 80 years (adjusted HR ranged from 1.89 to 1.91). Meanwhile, the association between higher BMI and the increased risk of ATR was greatest in the 20- to 39-year age group (adjusted HR, 3.90; 95% CI, 3.31–4.49) and decreased as age increased. The association of higher BMI and the increased risk of Achilles tendon problems was greater in men for AT (male vs. female: adjusted HR, 2.50 vs. 2.01) and ATR (4.90 vs. 2.08). The difference in adjusted HR between men and women was greater in ATR. Detailed IRs of AT and ATR for each BMI group according to age and sex are shown in Supplementary Table 3.

Regarding frequency of high-intensity exercise, the association between higher BMI and the increased risk of Achilles tendon problems was greater in the subjects who performed high-intensity exercise frequently than in those who did not for AT (adjusted HR, 2.29 vs. 1.91) and ATR (4.39 vs. 3.15).

DISCUSSION

Our study revealed that higher BMI was significantly associated with the increased risk of AT and ATR; it showed a stronger association with ATR. Conversely, higher WC was significantly associated with the increased risk of AT, but not ATR. For each BMI group, the association between higher BMI and the risk of AT was higher among individuals with higher WC than those with lower WC, be-

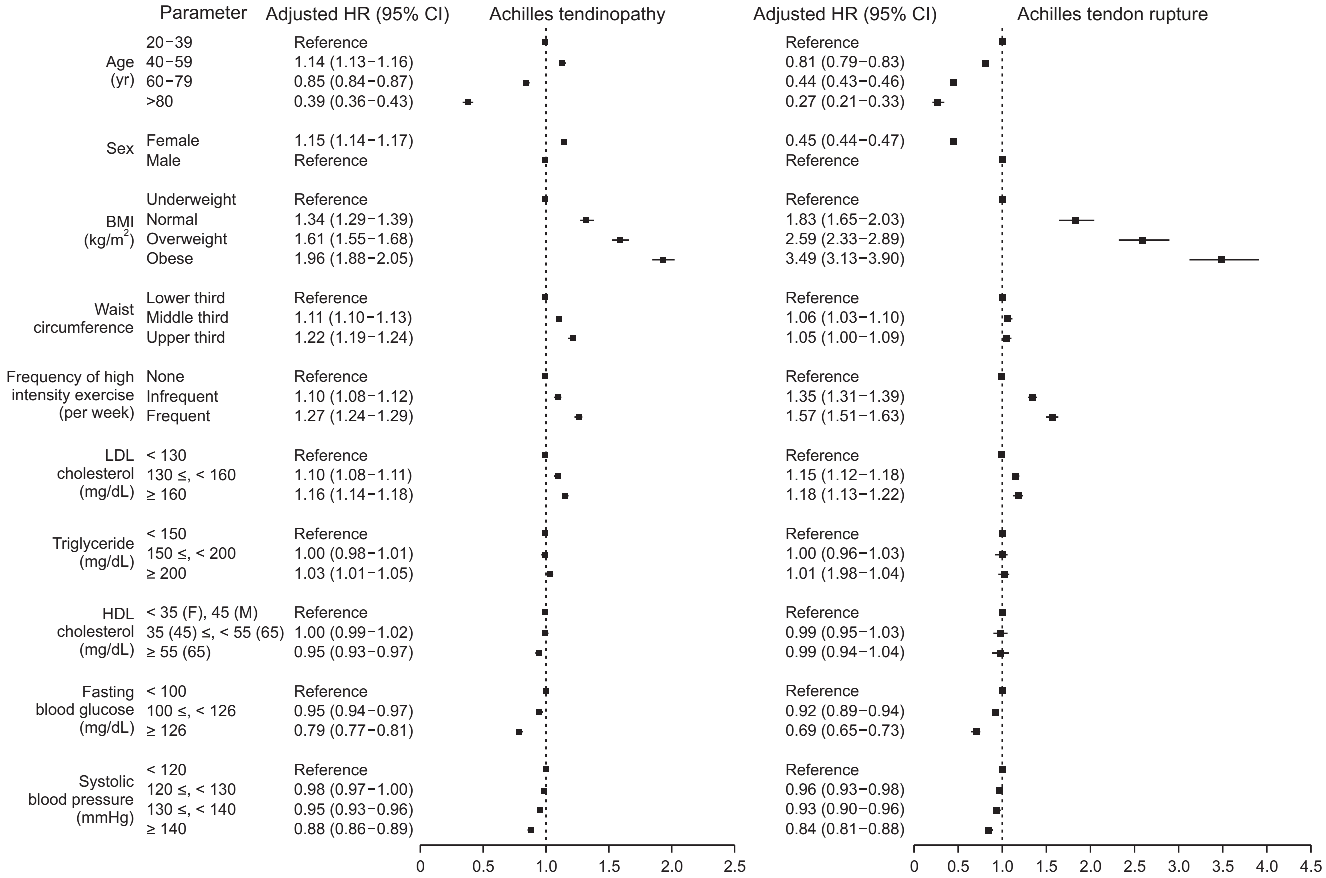

Fig. 2. Forest plot demonstrating adjusted hazard ratios for all included variables with regard to Achilles tendinopathy and tendon rupture. HR: hazard ratio, CI: confident interval, BMI: body mass index, LDL: low-density lipoprotein, HDL: high-density lipoprotein.

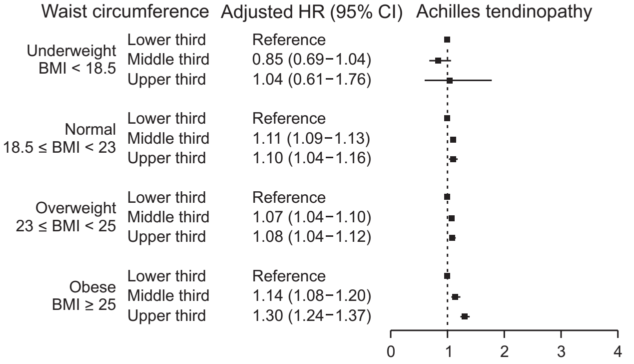

Fig. 3. Forest plot showing the association of body mass index (BMI; kg/m^2) and waist circumference with the risk of Achilles tendinopathy. HR: hazard ratio, CI: confident interval.

ing most significant in individuals with both higher BMI and higher WC. We also confirmed that the association between higher BMI and the increased risk of AT or ATR varied according to the subjects' age, sex, and physical activity level.

Current evidence suggests obesity be an important risk factor for Achilles tendon problems; however, the association between higher BMI and AT is still inconclusive despite several studies.[5-20] A recent systematic review[21] concluded that no scientific evidence supports the association of body weight or BMI with AT. Among the six included studies,[11,14,15,17,19,20] only one[11] showed a positive association between obesity and AT, while the others[14,15,17,19,20] reported a negative association. For ATR, it is impossible to evaluate the association as only few relevant studies have been conducted to date.[16,31-34]

During our literature search, we found that BMI was used as the parameter reflecting the severity of obesity in most studies, whereas it has been established that WC or WC coupled with BMI predicts obesity-related health risk better than BMI alone.[35,36] Therefore, we aimed to evaluate (1) the association of WC with the risk of AT or ATR, and (2) the effect of higher WC on higher BMI in the risk of Achilles tendon problems. Furthermore, we recognized that previous studies were mostly case-control studies that included a small number of subjects, which inhibited the evaluation of the IR or risk ratios, while our study is a

Table 4. Adjusted Hazard Ratios (with 95% Confidence Interval) from Subgroup Analysis According to Age, Sex, and Frequency of High Intensity Exercise

Variable	Underweight (BMI < 18.5 kg/m^2)	Normal (18.5 ≤ BMI < 23 kg/m^2)	Overweight (23 ≤ BMI < 25 kg/m^2)	Obese (BMI ≥ 25 kg/m^2)
Achilles tendinopathy				
All subjects	Reference	1.34 (1.29–1.39)	1.61 (1.55–1.68)	1.96 (1.88–2.05)
Subgroup analysis according to age (yr)				
20–39	Reference	1.24 (1.17–1.31)	1.57 (1.47–1.67)	1.90 (1.77–2.02)
40–59	Reference	1.32 (1.27–1.42)	1.56 (1.45–1.67)	1.89 (1.76–2.03)
60–79	Reference	1.30 (1.16–1.45)	1.56 (1.39–1.75)	1.91 (1.70–2.14)
≥ 80	Reference	0.72 (0.51–1.04)	0.91 (0.60–1.37)	1.03 (0.91–1.17)
Subgroup analysis according to sex				
Female	Reference	1.45 (1.37–1.53)	1.72 (1.62–1.83)	2.01 (1.88–2.14)
Male	Reference	1.52 (1.35–1.70)	1.92 (1.71–2.16)	2.50 (2.22–2.82)
Subgroup analysis according to frequency of high-intensity exercise per week				
None	Reference	1.24 (1.17–1.31)	1.52 (1.43–1.62)	1.91 (1.79–2.03)
Infrequent (≤ 2)	Reference	1.31 (1.21–1.42)	1.60 (1.47–1.74)	1.93 (1.77–2.11)
Frequent (≥ 3)	Reference	1.47 (1.32–1.64)	1.88 (1.68–2.10)	2.29 (2.05–2.56)
Achilles tendon rupture				
All subjects	Reference	1.83 (1.65–2.03)	2.59 (2.33–2.89)	3.49 (3.13–3.90)
Subgroup analysis according to age				
20–39	Reference	1.77 (1.52–2.02)	2.78 (2.37–3.19)	3.90 (3.31–4.49)
40–59	Reference	1.79 (1.49–2.15)	2.50 (2.07–3.01)	3.31 (2.74–4.01)
60–79	Reference	1.59 (1.17–2.16)	1.68 (1.23–2.30)	2.03 (1.48–2.80)
≥ 80	Reference	1.11 (0.42–2.94)	1.08 (0.36–3.22)	0.71 (0.22–2.32)
Subgroup analysis according to sex				
Female	Reference	1.61 (1.37–1.90)	1.75 (1.46–2.10)	2.08 (1.72–2.50)
Male	Reference	2.40 (1.86–3.10)	3.72 (2.87–4.82)	4.90 (3.78–6.36)
Subgroup analysis according to frequency of high-intensity exercise per week				
None	Reference	1.83 (1.60–2.10)	2.46 (2.14–2.84)	3.15 (2.72–3.64)
Infrequent (≤ 2)	Reference	1.75 (1.43–2.14)	2.64 (2.15–3.25)	3.78 (3.07–4.65)
Frequent (≥ 3)	Reference	2.26 (1.70–3.02)	3.34 (2.50–4.47)	4.39 (3.28–5.89)

Covariates were age (excluded in subgroup analysis according to age), sex (excluded in subgroup analysis according to sex), frequency of high-intensity exercise (excluded in subgroup analysis according to frequency of high-intensity exercise per week), LDL cholesterol, triglyceride, HDL cholesterol, fasting blood glucose, and systolic blood pressure.
BMI: body mass index, LDL: low-density lipoprotein, HDL: high-density lipoprotein.

nationwide population-based cohort study that included a large number of subjects without bias toward a specific occupation group or age, allowing the evaluation of IR and risk ratios. Klein et al.10) reported that subjects with BMI > 30 kg/m^2 was 2.6 to 6.6 times more likely to present with AT through a matched case-control study. A cross-sectional study by Frey and Zamora8) revealed that subjects with BMI ≥ 25 kg/m^2 would be twice as more likely to have AT. On the contrary, Mahieu et al.14) and Milgrom et al.15) found no statistically significant association between BMI and AT for 69 male officer cadets following a 6-week basic military training and 1,405 male infantry recruits who underwent cold weather training. The study by Wezenbeek et al.20) prospectively evaluated 300 university freshmen students for 2 consecutive years and found no significant difference in BMI between those with AT and control. For ATR, a recent retrospective study by Noback et al.16) including 93 ATR reported no significant difference in BMI between the ATR and ankle sprain groups.

The significant association between higher BMI and the increased risk of AT can be explained by the theory that micro-traumatic tendinopathy of the Achilles tendon is a functional overload pathology, which can lead to a long-standing process of failed healing response. Previous *in vivo* studies37,38) mentioned that the increased absolute tendon load induced by higher BMI may result in low-grade inflammation by increased cytokine levels and the number of tenocytes. This low-grade inflammation could lead to marked proteoglycan production, which separates the collagen and disorganizes the matrix. Wearing et al.39) found that the mean cross-sectional area of the Achilles tendon of subjects with BMI > 25 kg/m^2 was 12% thicker. This structural changes in tendon might impair intratendinous fluid movement in response to load derived from higher BMI. Likewise, de Sá et al.40) mentioned that higher BMI negatively correlated with highly aligned collagen of the Achilles tendon by using ultrasound tissue characterization. Meanwhile, the significant association between higher BMI and the increased risk of ATR can be explained in a different way. Acute traumatic ATR is rather the resistance to sudden calf muscle contraction than functional overload pathology. The intensity of tensile force induced by sudden ankle dorsiflexion could be directly determined by the higher BMI as obese subjects tend to overload the musculotendinous structure with elevated rate and magnitude during movement.

In addition to the significant associations between higher BMI and the increased risk of Achilles tendon problems, we also found that a high central fat distribution (represented by a higher WC) was independently associated with the increased risk of AT, though this was not observed for ATR. These findings are consistent with a previous cross-sectional study by Gaida et al.41) that reported subjects with AT had greater waist-to-hip ratios and higher upper-body/lower-body fat mass ratios than those with normal tendons. WC has been studied as an important risk factor for other tendon pathologies such as rotator cuff tendinopathy or epicondylitis of the elbow. Our study also showed that a higher WC potentiated the association of higher BMI with the increased risk of AT. This is supported by the fact that central adipose tissue is a major endocrine and signaling organ that releases several bioactive peptides and hormones.25) As a result, the systemic states of chronic, subclinic, and low-grade inflammations may persist and act as prolonged disruptors of tendon homeostasis.25) This may have a detrimental effect on tendon healing and immune response to acute tendon injury.22) As not all subjects with higher BMIs are characterized by the presence of AT and higher BMI does not reflect the pattern of fat distribution, we suggest an advantage to measuring the WC when assessing the risk of AT.

Our data revealed that the association of higher BMI with the increased risk of Achilles tendon problems was greater in the subjects who frequently performed high-intensity exercise. Generally, AT and ATR are more likely to occur in highly physically active subjects. Physical activity with an increased metabolic demand requiring more blood supply induces relative hypoxia, promoting a “switch” in the collagen matrix synthesis.20) As the metabolic demand can be further increased with higher BMI, overweight runners can precociously develop AT and ATR due to increased stress and the unfavorable milieu of repair.5) Likewise, our finding that higher BMI was more associated with the increased risk of ATR in younger subjects might be associated with a generally higher frequency of physical activity in younger subjects. In younger subjects, accidental events may be more common owing to their generally higher activity levels than elderly subjects.

Our study is not without limitations. First, the diagnosis of AT or ATR relied on the administrative claims data reported by physicians or hospitals, similar to other registry-based studies. Second, it would have been greater if we included the existence of either inflammatory disease (e.g., rheumatoid arthritis) or diabetes, and the use of corticosteroid as covariables. Third, we cannot entirely rule out the possibility that our data may have included subjects with open ATR associated with direct laceration or cutting injury. A direct ATR with an open wound has a vastly different injury mechanism, which is not influenced by any of the risk factors mentioned in our study. Furthermore, we could not distinguish between chronic and neglected ATR from acute traumatic ATR. Lastly, the present study lacks information on the diagnosis of insertional or non-insertional AT, although it has a slightly different disease nature, characteristics, and treatment.[42)]

In conclusion, higher BMI was significantly associated with the increased risk of AT and ATR. This association was greater with the risk of ATR than with the risk of AT. Conversely, WC was significantly associated with the increased risk of AT, but not ATR. Higher WC potentiated the association between higher BMI and the risk of AT compared with an average or a lower WC. This implies the greater importance of a high central fat distribution contributing to the development of AT in obese subjects. Furthermore, our results suggest that AT may be a metabolism-related degenerative disease, while ATR may be less likely attributed to inflammatory changes, but rather to mechanical force induced by sudden physical movement, whereby intensity could be directly related to the subject's BMI.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGEMENTS

In remembrance of Woon Hyuk Lee (1982–2020), Jun Young Choi is grateful for his help with analyzing data and English editing.

This research was Jun Young Choi's Ph.D dissertation.

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SUPPLEMENTARY MATERIAL

Supplementary material is available in the electronic version of this paper at the CiOS website, www.ecios.org.

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