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Relationships between cardiovascular disease risk factors and Achilles tendon structural and mechanical properties in people with Type 2 Diabetes

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SUMMARY

Background. Patients with diabetes have 44% greater risk of tendon rupture requiring hospitalisation. Despite this, in vivo research of the associations of diabetes and other cardiovascular disease risk factors on structural and mechanical properties of the Achilles tendon are sparsely studied.

Methods. Inactive individuals with type 2 diabetes (n=33) underwent ultrasound and shear wave elastography imaging of their Achilles tendons bilaterally to measure thickness and shear wave velocity (SWV), an index of tendon elastic modulus. In a separate session, participants underwent assessment of body composition, cardiorespiratory fitness and blood biomarkers. Seven inactive individuals without type 2 diabetes were recruited for comparison of tendon structural and mechanical properties.

Results. In participants with diabetes, free tendon SWV displayed large negative correlations with hip circumference (r=-0.67, P <0.001), waist circumference (r=-0.59, P <0.001) and body mass index (r=-0.52, P <0001), and a moderate positive correlation with VO_2peak (r=0.34, P =0.006). SWV was lower in participants with diabetes taking statins compared to not taking statins (Free tendon: median difference 8%, P=0.004); insertion: 11%, P =0.001). Compared to the control group, the diabetes group had thicker Achilles free tendon (median difference 15%, P<0.001) and Achilles insertion (17%, P=0.006), but no differences in SWV (P=0.490 or 0.577 respectively).

Conclusions. Achilles tendons from individuals with type 2 diabetes were thicker compared to inactive individuals without diabetes. Adiposity, statin use and low cardiorespiratory fitness were associated with inferior Achilles tendon mechanical properties in people with diabetes.

KEY WORDS

Adiposity; elastic modulus; enthesis; lipids; stiffness; tendinopathy

BACKGROUND

Individuals with diabetes are at greater risk of various musculoskeletal disorders, including more than three times the odds of tendinopathy (1) and 44% greater risk of tendon rupture (2). Impairments in tendon healing (3) may also contribute to the negative impact of diabetes on outcomes of tendon surgery, such as for the rotator cuff. The underlying biological mechanisms by which diabetes alters connective tissue mechanical and structural properties, especially tendon, are the subject of ongoing investigations (4). Hyperglycaemia is generally believed to increase tendon stiffness by accumulation of advanced glycation end products (AGEs) which modify crosslinking within or across collagen fibres. However, animal studies provide conflicting evidence of decreased or no change in tendon stiffness in response to chronic induced hyperglycaemia, (4) and there are very few studies that consider the mechanical properties of tendons in people with diabetes. Complicating this further, type 2 diabetes is most common in obese and sedentary patients, hence shared risk factors, including dyslipidaemia (5) may also contribute to tendon abnormality. The high prevalence of tendon abnormalities in people with diabetes as well as among overweight and obese people (6) deserve further investigation of these relationships.

Tendon mechanical properties are classically inferred from the relationship between the force applied to the tendon and its associated displacement. These measures, collected during maximal isometric contractions (7) or during walking, (8) are time consuming and can be problematic in patient cohorts due to deficits in strength (7, 8) or differences in moment arm (7). There is a growing interest in ultrasound elastography in the evaluation of healthy and pathological tendon (9, 10). Shear wave elastography uses ultrafast imaging to measure the speed of propagation of shear waves generated by acoustic radiation force from the ultrasound transducer in the tissue of interest (11). Shear wave velocity (SWV) is linked to the shear (or elastic) modulus, with the shear wave traveling at greater speed in stiffer tissues (11). By testing cadaveric Achilles tendons, it was found that the instantaneous shear modulus (measured over time as load was progressively increased) was highly correlated (R^2 =0.95) with the apparent elastic modulus derived at the same instants during the tensile test (12). The clinical utility of shear wave elastography in the study of patients with diabetes has not been extensively studied. (13, 14)

The current study aims were: 1) To examine, in participants with type 2 diabetes, the relationships between Achilles tendon structural and mechanical properties and cardiovascular disease risk factors, such as age, obesity, physical activity, dyslipidaemia and glucose control; 2) To compare structural and mechanical properties of the Achilles tendon between participants with or without type 2 diabetes (balanced for age and physical activity levels). We hypothesised that SWV (an index of tendon elastic modulus), and thickness would be greater in Achilles tendons from participants with type 2 diabetes compared to participants without diabetes.

MATERIALS AND METHODS

Inactive adults with diabetes enrolling in a randomised controlled trial investigating the efficacy of exercise training on glucose control were invited to participate in the current study. Participants were eligible if aged 18 to 80 years, confirmed to have type 2 diabetes by their medical practitioner and with a fasting glucose level ≥ 7.0mmol/L or glycated haemoglobin (HbA_{1c}) ≥ 6%. Participants were excluded if they already met physical activity guidelines (i.e., participated in more than 150 minutes of moderate or 75 minutes of vigorous physical activity per week which is equivalent to 750 MET-mins per week)[15] or had any cardiac, respiratory, neurological or orthopaedic contraindications to exercise training. Recruitment within Brisbane, Australia was by social media, university newsletters and advertising through local clinics, Diabetes Queensland and Diabetes Australia.

A small cohort of inactive adults without diabetes were recruited by social media as controls for cross-sectional comparison of ultrasound and elastography variables. To be eligible, control participants must not have been diagnosed with diabetes or participate in more than 150 minutes of moderate physical activity or 75 minutes of vigorous physical activity per week which is equivalent to 750 MET-mins per week. Participants were excluded if HbA_{1c} was greater than 6%, assessed using a Point of Care Diagnostics (POCD) A1CNow+ portable analyser. Ethical approval was by University of Queensland Institutional Human Research Ethics (Approval 2015000164 and 2013001448). All participants provided verbal and written consent prior to testing. This study meets the ethical standards of this journal. (16)

Achilles tendon ultrasound and elastography assessment

Ultrasound and shear wave elastography examinations were performed using an Aixplorer Ultrasound Scanner (version 9.3; Supersonic Imagine, Aix-en-Provence, France) and linear transducer (4-15 MHz, Vermon, Tours, France) by a single examiner with 2.5 years of elastography experience. Methodological aspects including participant posi-

tion, imaging locations and data extraction were consistent with a previous study of healthy and symptomatic Achilles tendinopathy. (17) This study reported strong (Intraclass correlation coefficient (ICC) 0.97) and modest (ICC 0.71) reliability for thickness and SWV of the Achilles free tendon respectively in six participants (12 tendons tested 48 hours apart). (17)

Upon arrival, participants were positioned in prone lying with their feet freely-hanging over the edge of a plinth. Participants rested in this position for five minutes prior to elastography measurement. The resting ankle angle was measured using a handheld goniometer, with plantargrade assigned a reference value of 90° and lower values indicating more plantarflexion. Participants were asked to remain completely relaxed during testing. Left and right Achilles tendons were measured in a randomised order. Measurement of the Achilles insertion preceded that of the Achilles free tendon.

The ultrasound transducer head was aligned in the longitudinal plane with collagen fibres, applying minimal pressure. First, two B-mode images were taken at each location, from which tendon thickness was measured using the inbuilt Aixplorer distance function. The maximum perpendicular distance between anterior and posterior tendon boundaries was measured in two locations: midway between the soleus musculotendinous junction and Achilles insertion (free tendon) and immediately proximal to the Achilles insertion onto the calcaneum (insertion). Following this, the elastography tendon preset was selected and the elastogram size maximised. The transducer was held for ~10 seconds, and repeated 2-3 times at each location. If low image quality was observed, penetration was increased or a reduced elastogram size was adopted.

Elastography clips (sampling rate 1.6 Hz) were converted into a series of PNG images (approximately 20 images) and processed using customised Matlab scripts (R2016a; The Mathworks, Natick, MA, USA). Standardised procedures for selection of regions of interest (ROI) were performed by tracing within the peritendon boundaries on the overlaid B-mode image. Free tendon ROIs were typically 30-40mm in length, while for the Achilles insertion, a ROI length of 5-10mm was measured immediately proximal to junction of the deep Achilles tendon and the calcaneum. The mean SWV (in m/s) and the percentage of all pixels without colour, termed signal void, were averaged over consecutive images. In addition, the thickness of subcutaneous fat overlying the free Achilles tendon, not including peritendon or skin, was measured in mm. These technical parameters were measured as previous evidence suggests greater acquisition depth, thick superficial fat layers and shear wave attenuation, may affect measurement of SWV. (17)

Calf muscle function

Following ultrasound examination, all participants completed a clinical test of calf muscle function on each leg separately. The participant stood barefoot on one leg using the wall for very light support. Using a metronome (0.75Hz), the participant performed unilateral heel rises until they first noted pain in the calf or Achilles region, or until they performed 30 complete repetitions. The number of repetitions was highly, positively correlated with SWV in a previous study of participants with Achilles tendinopathy. (17)

Blood biomarkers

After an overnight fast, a venous blood sample was collected from the antecubital vein of participants with diabetes using standardised phlebotomy practice into 6ml serum and EDTA tubes (Becton, Dickinson & Company, Franklin Lakes, NJ, USA). Following brief storage on ice (< ten minutes), whole blood was extracted from the EDTA tube to measure HbA_{1c} using an immunoturbidimetric method. The serum tube was left at room temperature for thirty minutes before centrifugation with the remaining blood in the EDTA tube (ten minutes at 4°C, 2500 RPM). Serum and plasma samples were separated into aliquots and immediately stored at -80°C until analysis. Serum lipid profile (total cholesterol, low density lipoprotein (LDL), high density lipoprotein and triglycerides) and fasting plasma glucose were assessed using manufacturer supplied kits in an auto analyser (Randox RX daytona+, USA).

Cardiorespiratory fitness test

Participants with diabetes completed a graded exercise test to exhaustion to determine cardiorespiratory fitness (VO_2peak). Participants were asked to avoid exercise, caffeine and tobacco in the 24h prior to the exercise stress test as well as avoiding food in the 2h prior to the test. The test was performed on a treadmill, or on a cycle ergometer if unable to walk/run. Standardised verbal encouragement was given throughout the test. Oxygen consumption was measured using either the Parvo (Parvo Medics TrueOne, Sandy, Utah, USA) or Metamax (Metamax II system, Cortex, Leipzig, Germany) metabolic systems.

Demographic and clinical information

All participants provided demographic and clinical information (age, sex, smoking, diabetes duration, medications, comorbidities). Body mass, height, waist and hip circumference were measured in participants with diabetes using standardised protocols. (18) Participants completed the International Physical Activity Questionnaire (IPAQ), which provided information about physical activity levels across

leisure, domestic, work and transport domains during the preceding week. (19) Scores on walking, moderate-intensity and vigorous-intensity activity were combined to describe the overall level of activity, measured in metabolic equivalent minutes per week (met mins). Self-reported Achilles pain and disability were evaluated using the Victorian Institute of Sport Achilles (Sedentary) (VISA-AS) assessment recently adapted for non-athletic populations. (20) Participants were asked to consider any symptoms in the area of the Achilles tendon on either leg. Total scores were reported out of 100, with lower scores indicating worse pain or disability. Participants with diabetes were not excluded if they experienced lower limb musculoskeletal symptoms.

Statistical analysis

Data were summarised as count (%), mean ± SD or median [IQR]. Scatterplots and Pearson's correlation coefficients were used to explore associations between Achilles SWV or thickness and cardiovascular disease risk factors in participants with diabetes. Correlations with serum lipids were performed separately for participants taking or not taking lipid lowering (statin) medication. Correlation coefficients (r values) above 0.5 were considered large, 0.3-0.5 as moderate or 0.1 to 0.3 as small.[21] Diabetes and control groups were compared using two-sample Wilcoxon rank-sum (Mann-Whitney) tests or two-sample t tests. Wilcoxon rank-sum was also used to compare tendon SWV and thickness between participants with diabetes taking or not taking statins. Both legs were included in analyses of tendon thickness, SWV, void, ankle angle and calf muscle function. All analyses were performed using Stata13.1 (StataCorp, USA).

RESULTS

Subject variables

Thirty-three participants with diabetes, aged between 34 and 78 years, with a median 7 years since diagnosis (range 6 months to 23 years), median HbA_{1c} of 7.83 % [IQR 7.12, 8.94 %] and a median fasting blood glucose of 7.99 mmol/L [IQR 6.66, 9.41 mmol/L] were recruited. The majority were taking oral anti-hyperglycaemic (81.8%), while 18.2% were on insulin. The duration of diabetes was longer (P=0.01) for participants on insulin (median [IQR]: 19.5 years [15,20] years) than participants not on insulin (5 years [3, 12] years). Fifty-five percent of participants with diabetes were taking lipid lowering (statin) medications (Crestor, Simvastatin, Rosuvastatin, Caduet, Lipitor, Vytorin, Crosuva, Cavstat; doses 5-40mg). Median and IQR values in mmol/L for total cholesterol, HDL cholesterol, LDL cholesterol and triglycerides were 4.3 [3.6, 5.1], 1.16 [0.97, 1.3], 2.3 [1.67, 2.74] and 1.21 [1.00, 1.72] respectively.

Seven participants without diabetes with a median HbA1c of 5.4 % [IQR 5.1, 6.0 %]) were recruited. There were no differences in age, BMI, smoking status, physical activity levels, pain or disability or calf muscle function between diabetes and control groups (**Table I**). However, the proportion of men and body mass were higher in the diabetes group (P=0.037, P=0.004 respectively).

Relationships between Achilles tendon properties and adiposity

Large negative correlations were observed between SWV of the Achilles free tendon and hip circumference (r=-0.67, P<0.001); waist circumference (r=-0.59, P<0.001) and BMI (r=-0.52, P<0.001) (**Figure 1**). For women, hip circumference was the best predictor of SWV (r=-0.80, p<0.001); whereas for men, waist was the best predictor of SWV (r=-0.67, p<0.001). SWV was moderately correlated with subcutaneous fat thickness overlying the Achilles free tendon (r=-0.37, P =0.002). For the Achilles insertion, small to moderate correlations were observed between SWV and some measures of adiposity (r=-0.28, P=0.02 for BMI; r=-0.31, P=0.01 for subcutaneous fat thickness).

Small to moderate positive correlations were observed between thickness of the Achilles free tendon and hip circumference (r=0.33, P=0.029), waist circumference (r=0.33, P=0.027) and BMI (r=0.24, P=0.049). Relationships with adiposity were not observed for thickness of the Achilles insertion (r values ranging from -0.17 to 0.19, P>0.14).

Relationships between Achilles tendon properties and physical activity/fitness

Small and moderate positive correlations were observed between SWV of the Achilles free tendon and physical activity as measured by IPAQ (r=0.27, P=0.038) or VO_2peak (r=0.34, P=0.006) respectively (**Figure 2**). Positive relationships were suggested for the Achilles insertion (VO_2peak r=0.24, P=0.058). Relationships with physical activity/fitness were not observed for thickness of the Achilles free tendon or insertion (r values ranging from -0.19 to 0.20, P>0.11).

Relationships between Achilles tendon properties, statin use and serum lipids

Participants with diabetes taking statins had lower SWV (median difference 8%, P=0.004) and increased thickness (11%, P=0.029) at the Achilles free tendon and lower SWV at the Achilles insertion (median difference 11%, P=0.001) than participants not taking statins.

In participants with diabetes taking statins, SWV of the Achilles free tendon displayed moderate negative correla-

Table I. Summary data (count, mean (SD) or median [IQR] for diabetes and inactive control participants. Differences between groups were measured by two-sample Wilcoxon rank-sum tests, t tests or chi^2 tests. Both legs were included in analysis of tendon thickness, SWV, void, ankle angle and calf muscle function). IPAQ: International Physical Activity Questionnaire; VISA-AS: Victorian Institute of Sport – Achilles (Sedentary) Questionnaire.

	Controls n=7	Diabetes n=33	P
Demographic and clinical			
Female n (%)	6 (85.7%)	14 (42.4%)	**0.037**
Age (years)	55.6 ± 10.9	58.6 ± 9.0	0.444
BMI (kg/m2)	27.0 [26.2, 31.2]	33.4 [28.9, 38.8]	0.072
Body mass (kg)	75.0 [69.4, 81.7]	100.5 [87.0, 115.6]	**0.004**
Smoker n (%)	0 (0%)	4 (12.5%)	0.323
IPAQ (met-mins/wk)	190 [70, 315]	190 [60, 270]	0.786
VISA-AS (0-100)	100 [91, 100]	99 [91, 100]	0.256
Heel raise repetitions^	14.5 ± 5.5	14.5 ± 6.1	0.986
Resting ankle angle (°)^	62.4 ± 4.1	68.3 ± 4.9	**<0.001**
Ultrasound/elastography^			
Thickness: Free tendon (mm)	4.6 [4.2, 4.8]	5.3 [4.9, 6.2]	**<0.001**
Thickness: Insertion (mm)	3.8 [3.6, 3.9]	4.3 [3.8, 4.6]	**0.006**
Thickness: Subcutaneous fat (mm)	0.9 [0.7, 1.2]	1.6 [1.2, 1.9]	**0.002**
SWV: Free tendon (m/s)	11.6 [11.2, 11.9]	11.8 [10.6, 12.5]	0.490
SWV: Insertion (m/s)	10.4 [10.3, 10.8]	10.4 [9.5, 11.2]	0.577
Void: Free tendon (%)	0.1 [0.003, 0.4]	0.5 [0.002, 1.7]	0.310
Void: Insertion (%)	0.9 [0.2, 1.2]	0.35 [0.0, 2.9]	0.392

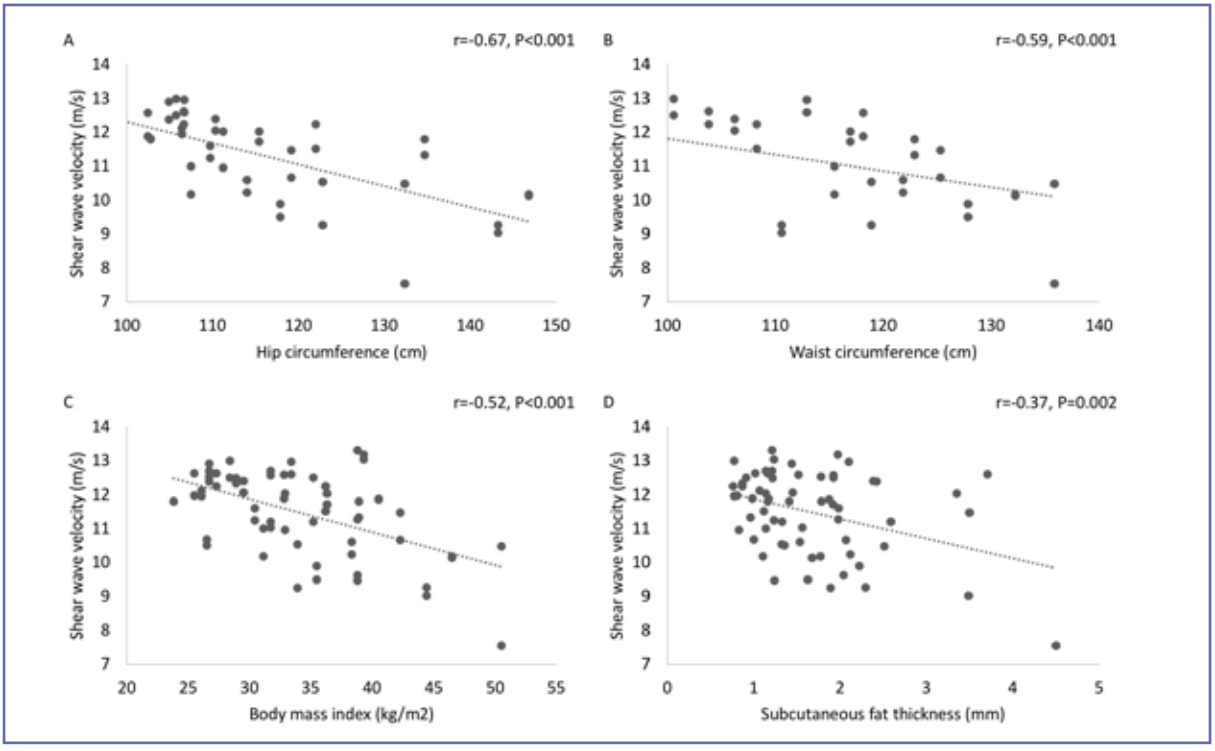

Figure 1: Correlations between shear wave velocity of the Achilles free tendon and A) hip circumference, B) waist circumference, C) body mass index and D) subcutaneous fat thickness overlying the free Achilles tendon in participants with diabetes.

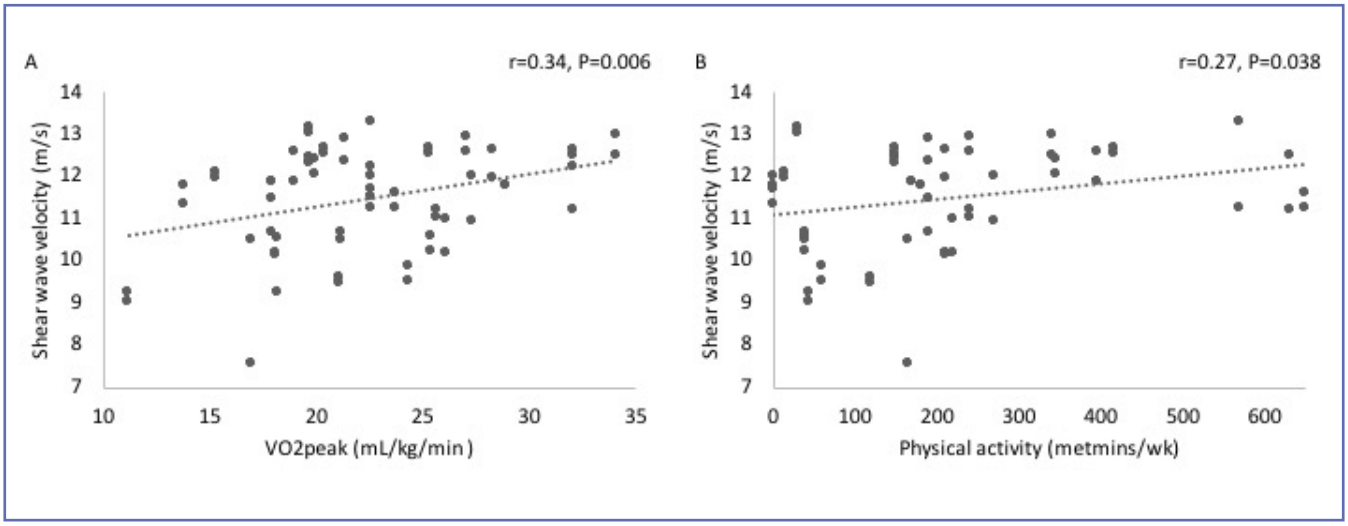

Figure 2: Correlations between shear wave velocity of the Achilles free tendon and A) VO_2peak, B) physical activity, measured by International Physical Activity Questionnaire (IPAQ) in participants with diabetes.

tions with total cholesterol (r=-0.40, *P*=0.02) and LDL cholesterol (r=-0.35, *P*=0.02), while relationships with serum lipids were not observed in those not taking statins (r values ranging from -0.07 to 0.20, *P*>0.36) (**Figure 3**). Relationships with serum lipids were not observed for SWV of the Achilles insertion in participants with diabetes taking or not taking lipids (r values ranging from -0.34 to 0.12, *P*>0.11). Relationships with serum lipids were not observed for thickness of the Achilles free tendon or insertion (r ranging from -0.32 to 0.29, *P*>0.07).

Relationships between Achilles tendon properties, age, glucose control and duration of diabetes

A small negative correlation was observed between Achilles free tendon SWV and age (r=-0.26, *P*=0.041), and a moderate positive correlation between Achilles free tendon thickness and age (r=0.35, *P*=0.004). Relationships between SWV or thickness and age were not were observed for the Achilles insertion (r values ranging from -0.15 to -0.06, *P*>0.23). There were no relationships between Achilles free tendon or insertion SWV or thickness, and HbA1c, fasting blood

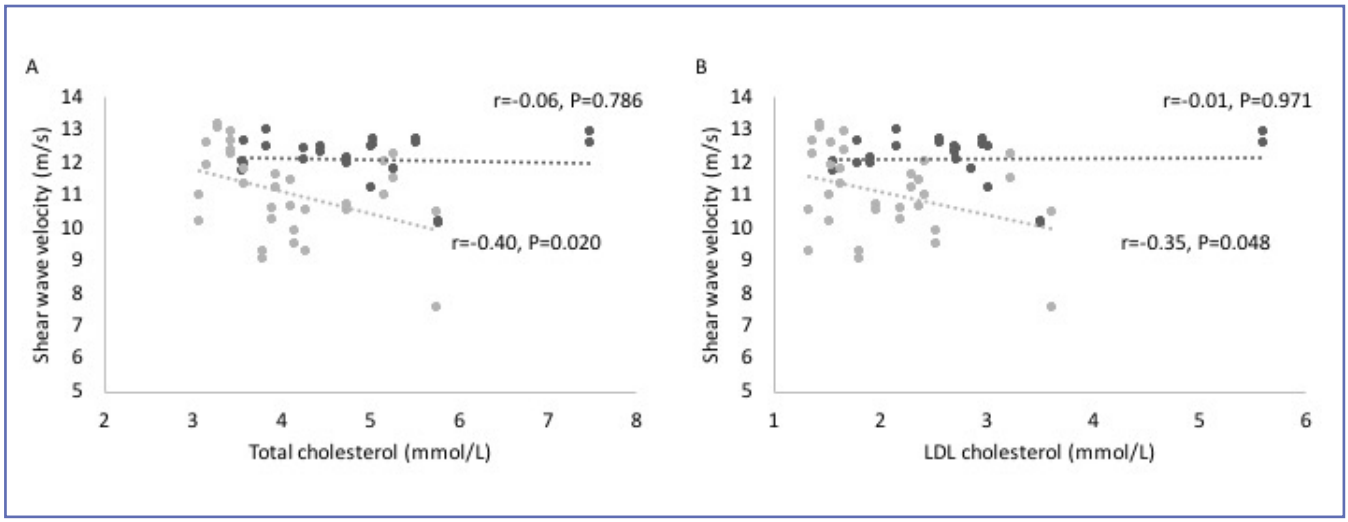

Figure 3: Correlations between shear wave velocity of the Achilles free tendon and A) Total cholesterol B) Low density lipoprotein (LDL), measured in participants with diabetes taking statins (light grey) or not taking statins (dark grey).

glucose or diabetes duration (r ranging from -0.22 to 0.23, P>0.097), with the exception of a moderate, negative correlation between Achilles insertion SWV and fasting blood glucose (r=-0.32, P=0.022) (**Figure 4**).

Effect of diabetes on Achilles tendon mechanical properties

Compared to inactive control participants, individuals with diabetes had greater tendon thickness at both the free tendon (median difference 15%, P<0.001, **Figure 5**) and insertion (median difference 17%, P=0.006) and much greater subcutaneous fat thickness measured overlying the Achilles free tendon (median difference 78%, P=0.002, **Table I**). No differences in SWV of the free tendon or insertion were found between diabetes and control groups (median difference 0-1.7%, P>0.49), although much larger variability was displayed for the diabetes group (**Figure 5**). The percentage signal void within the measured regions of interest did not differ between groups (P>0.31, **Table I**). Measurement of individual's freely-hanging position was found to be more dorsiflexed for the diabetes than control group (mean difference 5.9°, 95% CI 3.0 to 8.7; P<0.001).

DISCUSSION

The findings from this study advance our limited understanding of how diabetes affects Achilles tendon structural and mechanical properties. In line with our hypothesis, inactive individuals with type 2 diabetes had thicker Achilles free tendon and insertion than inactive individuals without diabetes. Contrary to our hypothesis, no effect of diabetes on SWV was observed, although large variability was observed in participants with diabetes. We propose that the variability in tendon structural and mechanical properties may reflect adverse effects of adiposity and dyslipidaemia, as well as potential protective effects of physical activity and fitness. Specifically, we observed in participants with diabetes that Achilles free tendon SWV displayed large negative correlations with measures of adiposity, moderate negative correlations with total cholesterol and LDL cholesterol, while small to moderate positive correlation with self-reported physical activity and cardiorespiratory fitness respectively. In contrast, Achilles free tendon SWV was not correlated with diabetes duration or measures of glucose control.

Our results are in partial agreement with other studies using elastography, which demonstrate that reduced tendon stiffness is not characteristic of all participants with diabetes. Using semiquantitative strain elastography, Evranos et al (2015) demonstrated that compared to controls, the relative stiffness of Achilles tendons was softer in participants with diabetes and foot ulcers, but not those with diabetes without foot ulcers. (14) Recently, Iyidir et al (2019) compared patients with type 2 diabetes with and without peripheral neuropathy and healthy controls using Acoustic Radiation Force Impulse elastography (13). Both diabetes groups had increased Achilles tendon thickness, whereas only the group with peripheral neuropathy had reduced SWV compared to controls. Conflicting conclusions are reported by studies that use classic methods to derive tendon stiffness. Couppe et al (2016) (7) reported that diabetes was associated with increased tendon elastic modulus, but no differences in absolute stiffness or tendon dimensions, while Petrovic et al (2018) (8) reported higher tendon stiffness in

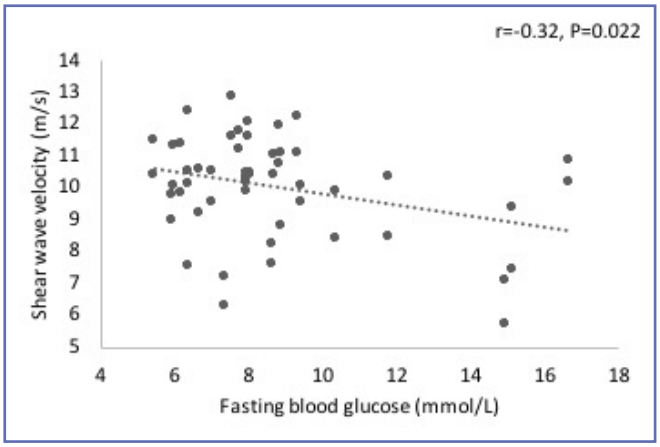

Figure 4: Correlation between shear wave velocity of the Achilles insertion and fasting blood glucose in participants with diabetes.

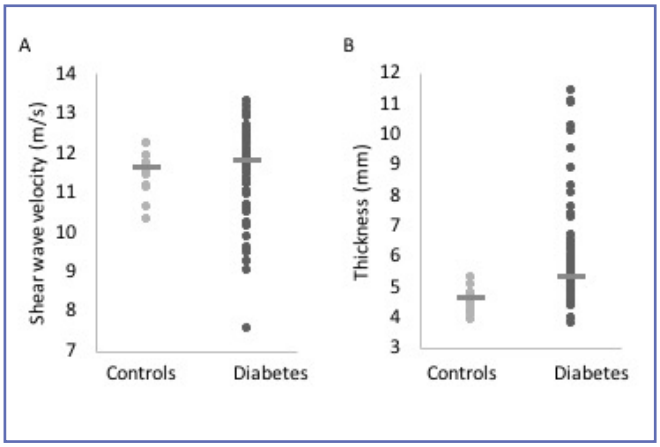

Figure 5: Individual data (and group median values) (A) shear wave velocity and B) thickness of the Achilles free tendon for control participants and participants with diabetes.

people with diabetes, however tendon dimensions were not measured. Technical differences as well as clinical variables may contribute to discrepancies with the current study. For example, both Couppe and Petrovic recruited participants with type 1 and type 2 diabetes and the mean BMI in their cohorts were lower than the current study of inactive individuals with solely type 2 diabetes.

Our findings are consistent with some, (3, 22, 23) but not all, (24, 25) animal models. Boivin et al (2014) (23) investigated the biomechanical properties of the Achilles tendon in db/db mice that develop early onset diabetes, are insulin resistant and obese. Their hypothesis was that tendons would be thicker and stiffer compared to control lean mice. Instead, they observed an increase in tendon diameter but decreases in tendon stiffness and elastic modulus, concluding that a combination of hyperglycaemia and obesity, rather than hyperglycaemia per se, may lead to severe reduction in tendon mechanical properties. (23, 24)

The relationships of tendon structural and mechanical properties with glucose control, adiposity and dyslipidaemia are not clearly established. (5) Our findings of large correlations between Achilles free tendon SWV and clinical measures of adiposity (r values ranging from -0.59 to -0.80) but not measures of glucose control, supports previous proposals that adiposity may be a stronger risk factor for tendinopathy than a diagnosis of diabetes. (5) In animals fed a high fat diet, obesity led to increased tendon cross-sectional area and decreased modulus. (26) It was speculated that the increase in cross-sectional area was an adaptation allowing the tendon to retain its ability to transmit load despite the decreased material property (modulus). In support of this proposal, we found Achilles free tendon SWV was more closely related to adiposity than tendon thickness, which may reflect that SWV is correlated with ultimate stress. (27)

Our finding of lower SWV in participants with diabetes taking statins may be a result of drug intervention or the pathological process necessitating statin therapy. Deterioration in Achilles tendon biomechanical properties has been observed in animals exposed to statins, (28) although a systematic review of statins and tendinopathy concluded there is limited evidence for causality between statin therapy and tendon rupture. (29) While we cannot conclusively distinguish these cause-effect relationships, the negative correlation between tendon SWV and total or LDL cholesterol and subcutaneous fat deposition around the tendon in individuals on statins, suggests it may reflect the pathological effects of lipids and cholesterol. (30) Previous research showed higher total cholesterol and LDL cholesterol in patients with Achilles tendon rupture versus case controls. (31)

Our finding that SWV was positively correlated with fitness and self-reported physical activity is supported by animal work, in which sedentary rats with induced diabetes had lower Achilles tendon elastic modulus, while aerobic physical training increased the modulus to approximate that of control groups inferring a protective effect of physical activity. (32) While tendon adaptation to exercise intervention in healthy adults is well documented, (33) tendon responses to training in individuals with diabetes or in obese populations are largely unknown. In their cross-sectional investigation of the role of adiposity and running on tendon properties, Abate et al (2012) found running was associated with greater Achilles tendon thickness in normal weight participants, but not in overweight sedentary participants. (6)

A strength of this study is the inclusion of a clinically representative sample of participants with type 2 diabetes, which included 18% classified as very severely or morbidly obese and comprehensive assessment of cardiovascular risk factors, tendon thickness and stiffness. In vivo testing of tendon mechanical properties in older patients with various durations of diabetes and comorbidities is recommended to provide insightful information that is currently not accounted for by invitro studies of hyperglycaemia. (24) We acknowledge that a larger number of male control participants would have improved the statistical strength and provided more certainty regarding the effect of diabetes. We also acknowledge the infancy of shear wave elastography for evaluation of tendon mechanical properties and highlight several technical considerations. First, current commercially available shear wave elastography systems ignore viscous properties, which may be altered in participants with diabetes. Second, the degree to which the group velocity of a shear wave is affected by tendon thickness (a thicker tendon would be expected to exhibit a higher SWV) due to guided wave propagation is not known. (34) Third, whether signal void represents an attenuation artefact or reflects matrix disorganisation is not currently known, although the percentages were much smaller than those reported in participants with symptomatic Achilles tendinopathy. (17)

Assessment of tendon SWV in people with diabetes could provide important clinical information about an individual's tendon health, complementary to measurement of tendon thickness. Previous study suggests elastography can discover small changes in the mechanical properties of tendon that are not evident on B-mode evaluation due to the same echogenicity of the surrounding healthy tissues, thus providing information regarding early diagnosis of tendon pathology. (10) Future research is needed to evaluate whether tendon SWV can predict debilitating tendon ruptures in high risk groups such as participants with diabetes.

In summary, Achilles tendons from inactive individuals with type 2 diabetes were thicker than those from inactive individuals without diabetes. Large variability in tendon SWV

was observed in participants with diabetes, with lower SWV (indicating inferior tendon material properties) associated with greater adiposity, statin use, dyslipidaemia and lower physical activity/fitness.

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