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Development of shoulder pain with job-related repetitive load: mechanisms of tendon pathology and anxiety

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Background: The paucity of longitudinal clinical studies limits our understanding of the development of shoulder pain with repetitive shoulder tasks, and its association with underlying mind and body mechanisms. Tendon thickening characterizes painful shoulder supraspinatus tendinopathy, and the perception of pain can be affected by the presence of psychological factors such as anxiety and depression. This study determined the incidence of shoulder pain in novice individuals exposed to repetitive shoulder tasks, and the associated change in outcomes of supraspinatus tendon morphology and measures of anxiety and depression.
Methods: We recruited dental hygiene (DH) students ($n = 45$, novice and exposed to shoulder repetitive tasks) and occupational therapy (OT) students ($n = 52$, novice, but not exposed to shoulder repetitive tasks), following them over their first year of training. We measured shoulder pain, supraspinatus morphology via ultrasonography, and psychosocial distress via the Hospital Anxiety and Depression Scale. We compared the incidence of shoulder pain (defined as a change of visual analog scale for pain score greater than the minimal clinically important difference) between DH and OT students using Fisher exact test. We used mixed effects models to longitudinally compare the change in outcomes between 3 groups: DH students who develop and did not develop shoulder pain, and OT students.
Results: The incidence of shoulder pain is higher in DH students (relative risk = 4.0, 95% confidence interval [CI] 1.4, 11.4). After 1 year, DH students with pain had the greatest thickening of the supraspinatus (0.7 mm, 95% CI 0.4, 0.9). The change in supraspinatus thickness of DH students with pain was greater than both DH students with no pain (0.4 mm, 95% CI 0.1, 0.8) and OT students (0.9 mm, 95% CI 0.5, 1.2). Anxiety score increased 3.8 points (95% CI 1.6, 5.1) in DH students with pain, and 43% of DH students with pain had abnormal anxiety score at 1 year (relative risk = 2.9, 95% CI 1.0, 8.6).

The institutional review board of the University of Southern California approved this study (HS-15-00004 and HS-16-00414).

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Conclusion: Our results provide support for the theoretical model of repetitive load as a mechanism of tendinopathy. The supraspinatus tendon thickens in the presence of repetitive tasks, and it thickens the most in those who develop shoulder pain. Concurrently, anxiety develops with shoulder pain, indicating a potential maladaptive central mechanism that may impact the perception of pain.

Level of evidence: Level I; Prospective Cohort Design; Prognosis Study

Keywords: Supraspinatus; tendinopathy; anxiety; pain; shoulder

Shoulder pain is a significant health problem with a prevalence of approximately 25% in the general population.[18] Repetitive mechanical overload is a main factor theorized to predispose an individual to tendon-related pain.[6,7,16,28] At the shoulder, rotator cuff tendon thickening occurs in response to repetitive loading.[15,19,22,23,26,27,31] An increase in tendon dimension may be an early indicator for the development of shoulder pain, as individuals with tendinopathy have been shown to have thicker supraspinatus tendons.[10,23] An increased thickness of the supraspinatus tendon causes the tendon to occupy a greater portion of the subacromial space,[22,23] which increases the chance of tendon compression and potentially pain.[4,8,13] However, it is important to note that structural changes have also been observed in asymptomatic individuals,[1] which limits our understanding of the interrelationships among repetitive loading, morphologic changes in the supraspinatus tendon, and shoulder pain development.[7]

Dental hygienists have repetitive work demands, including prolonged bilateral static postures and bilateral muscle submaximal contractions, along with limited rest periods.[9] These factors may predispose and explain the high prevalence of shoulder pain in dental professionals.[9] Previous work has found that repetitive loading increases tendon thickness in samples of overhead athletes, as well as symptomatic and asymptomatic populations.[15,19,22,23,26,27,31] Repetitive loading during bilateral tasks results in increased thickening of the supraspinatus bilaterally owing to constant tendon remodeling.[31] History of shoulder pain or current pain exacerbates morphologic tendon changes after period of acute loading[22,27] and decreased subacromial space[22] compared with healthy controls. Although it is clear that repetitive mechanical loading leads to macromorphologic tendon changes, it is unknown how tendon changes relates to the development of pain, because these factors have not been examined concurrently in longitudinal studies.

Shoulder pain negatively impacts function, and chronic pain can lead to psychosocial distress. Approximately a quarter of patients with shoulder tendinopathy report anxiety and depression.[34] Patients with an acute onset of musculoskeletal pain and negative psychosocial factors are more likely to have worse clinical outcomes and progress toward chronic pain.[3,34] Furthermore, psychosocial distress can contribute to a heightened pain experience in those with shoulder pain[34] and may partially explain the high 1-year continued prevalence of symptoms in patients with chronic shoulder pain.[18,33] Understanding the concurrent onset of pain and psychosocial distress will inform the body and mind relationship in shoulder pain development.

The primary aims of this study were to (1) determine the incidence of shoulder pain in novice individuals exposed to repetitive occupational shoulder tasks and (2) determine changes in supraspinatus tendon thickness associated with the development of shoulder pain. The secondary aim was to determine the changes subacromial space occupation ratio, shoulder function, anxiety, and depression associated with the development of shoulder pain.

Material and methods

Participants

We recruited participants as for a prospective longitudinal cohort study aimed at identifying pain and tissue morphologic changes at the shoulder in an at-risk population of dental hygiene (DH) students. Inclusion criteria were as follows: (1) age ≥18 years, and (2) enrolled in either the DH or occupational therapy (OT) program at the University of Southern California. Exclusion criteria was previous history of bilateral shoulder surgery. The Institutional Review Board of the University of Southern California approved this study. All participants reviewed and signed an informed consent before participating.

We recruited participants at the beginning of their academic program to ensure participants were novices and not previously exposed to specific professional training and tasks. The repetitive demands of the DH students' training included prolonged bilateral static and awkward postures, prolonged bilateral muscle submaximal contractions, and limited rest periods.[9] These factors may predispose and explain the high prevalence of shoulder pain in both DH students and dental professionals.[9] OT students were recruited as a comparator group because they have similar age, sex distributions, and professional training duration, but with lower repetitive or sustained work requirements relative to the shoulder.

The primary aim of this study was to identify a change in supraspinatus tendon thickness in participants exposed to repetitive shoulder tasks (DH students) that develop pain, as compared to DH student that did not develop pain, and to a control group unexposed repetitive shoulder task (OT students). Previous studies reported and effect size of 0.8 when comparing supraspinatus tendon thickness between patients seeking care for shoulder pain and healthy individuals[23] or 3.0 when comparing between sides of patients with unilateral shoulder tendinopathy.[10] In our power analysis, we used a smaller effect size (0.3) because our study aimed to assess tendon thickness changes at the onset of shoulder symptoms. With alpha level of 0.05, effect size of 0.3, and a high correlation among repeated measures (0.8), the required sample size to achieve 80% power is 102 participants.

Procedures

We collected data at the start (baseline) and the end (follow-up) of the first academic year. The follow-up occurred approximately 10 months after enrollment. Demographic information, including age, sex, height, weight, handedness, and ethnicity/race, were collected at baseline. At follow-up, participants reported whether they sustained any shoulder injuries (yes/no question). At each evaluation, we administered a visual analog scale (VAS) for shoulder pain, the University of Pennsylvania Shoulder Score (PENN) to capture functional loss at the shoulder, and the Hospital Anxiety and Depression Scale (HADS) to capture psychosocial distress; in addition, we collected ultrasonographic images of the supraspinatus and subacromial space. All outcomes, except HADS, were collected bilaterally.

An examiner with advanced training in musculoskeletal ultrasonographic imaging obtained B-mode images of the supraspinatus tendon and subacromial space using a diagnostic ultrasonography unit (LOGIQe; GE Healthcare, Wauwatosa, WI, USA) with a 4- to 12-MHz linear array transducer set at 10 MHz. Participants sat with neutral trunk and head posture and placed their hands on the ipsilateral posterior hip with the humerus in extension and external rotation (modified Crass position).[2] The ultrasound transducer was placed on the anterior aspect of the shoulder to capture the supraspinatus tendon. The transducer was oriented perpendicular to the supraspinatus tendon to collect the cross-sectional aspect of the tendon and the landmark of the biceps tendon. Two cross-sectional images were saved and used for the analysis.

Subacromial space images were captured with the participant in the seated position, arm by their side, with the hand resting on their thigh to minimize downward pull due to the weight of the arm.[23,27] The ultrasound transducer was placed on the most anterior aspect of the anterior acromial margin, as confirmed with palpation. The examiner oriented the long axis of the transducer parallel to the flat surface of the acromion, in the plane of the scapula. Two images of the humeral head and acromion were saved and used for analysis.

The examiner responsible for ultrasonography data collection and the investigator who measured the tendon thickness and acromiohumeral distance were blinded to pain development.

Primary outcomes

Shoulder pain

Participants slid a cursor to indicate their current level of shoulder pain when they move the arm to perform activities. We did not ask participants to perform activities during the evaluation. Participants indicated their symptoms between 2 extremes: “no pain at all” (corresponding to 0 points) to “pain as bad as it could be” (corresponding to 100 points). These types of visual numeric scales for shoulder pain are reliable in patients with shoulder injuries. The minimal clinically important difference is 11 points in patients with shoulder-related pain.[24]

Supraspinatus tendon cross-sectional thickness

The supraspinatus tendon borders were defined inferiorly as the first hyperechoic region above the anechoic articular cartilage of the humeral head and the hyperechoic superior border of the tendon before the anechoic subdeltoid bursa. We measured supraspinatus short-axis thickness (in millimeters) at 10, 15, and 20 mm lateral to the reference point of the lateral point of hyperechogenicity of the biceps tendon (Fig. 1, *A*).[23] The supraspinatus is relatively homogenous in dimension along the short axis of the tendon. Therefore, we averaged the cross-sectional thickness at each reference point. In the analysis, we used the average thickness value of the 2 ultrasonographic images collected at each time point.

We used 20 randomly selected ultrasonographic images to establish test-retest reliability. The supraspinatus tendon cross-sectional thickness intraclass correlation coefficient was 0.98 and the minimal detectable change at 90% confidence was 0.3 mm. These coefficients are similar to the ones reported by previous studies that used ultrasonography to measure supraspinatus tendon thickness.[23,27]

Secondary outcomes

Shoulder self-reported function

The PENN is a valid and reliable questionnaire developed to measure shoulder-related disability and loss of function (0-100; 100 = full function). The minimally clinically important

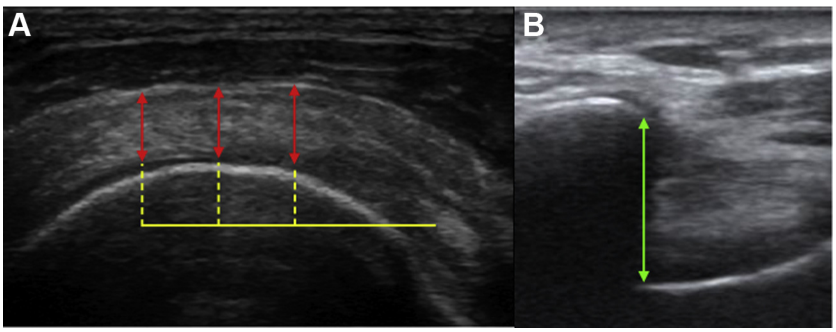

Figure 1 (**A**) Supraspinatus tendon cross-sectional thickness; the average thickness was calculated at 10, 15, and 20 mm from the biceps tendon (image not to scale). (**B**) Subacromial space measured as the distance between the acromion and the humeral head distance.

difference for the PENN score is 11.4 points in patients with shoulder-related pain.[14]

Subacromial space

The acromiohumeral distance, the shorter linear distance (in millimeters) between the superior aspect of the humeral head and the inferior aspect of the acromion, defined the subacromial space (Fig. 1, *B*). The average acromiohumeral distance from the 2 images was used for data analysis.

We used 20 randomly selected ultrasonographic images to establish test-retest reliability. The acromiohumeral distance intraclass correlation coefficients were 0.99, and the minimal detectable change at 90% confidence was 0.5 mm. These coefficients are similar to the ones reported by previous studies that used ultrasonography to measure subacromial space.[23,27]

Occupation ratio

The occupation ratio, defined as the portion of the subacromial space occupied by the supraspinatus tendon, was calculated by dividing the supraspinatus tendon cross-sectional thickness with the acromiohumeral distance. The occupation ratio is expressed as a percentage. The occupation ratio minimal detectible change is 6.3%.[27]

Psychosocial distress

The HADS is a 14-item questionnaire with 2 subscales—7 questions defining generalized anxiety and 7 questions for depression. Each subscale is scored out of 0-21 points, with higher scores indicating higher anxiety and depression.[5,35] The minimal detectable change, established in patients with cardiovascular diseases, is 3.8 for anxiety and 4.0 for depression.[32] A cutoff of 8 has the highest sensitivity and specificity in discriminating individuals with and without anxiety or depression.[5]

Statistical analysis

Statistical analyses were performed using SAS software (version 9.4; SAS Inc, Cary, NC, USA) and Stata Statistical Software (release 14; StataCorp, College Station, TX, USA). We compared the proportion of participants who developed shoulder pain between DH and OT students using Fisher exact test. In each group, a change of at least 11 points on the VAS for shoulder pain from baseline to follow-up on either the dominant or nondominant side defined participants who developed shoulder pain. We compared outcomes between 3 groups: the DH students who developed shoulder pain (DH-pain), the DH students who did not develop shoulder pain (DH–no pain), and the OT students. We used mixed effects linear models to compare the change (baseline to follow-up) of bilateral outcomes (supraspinatus cross-sectional thickness, acromiohumeral distance, occupation ratio, and PENN score) between groups (DH-pain, DH–no pain, and OT). A random subject effect was included to account for the correlated sides (dominant and nondominant). This model controlled for baseline values, and the interaction between group and side was evaluated. We used a general linear model to compare the change (baseline to follow-up) of the anxiety and depression subscale scores of the HADS (separately) between groups (DH-pain, DH–no pain, and OT), controlling for baseline values. We used a mixed effects model to compare the proportion of tendons that showed clinical signs of tendinopathy (change in thickness greater than 0.8 mm) between the DH-pain and DH–no pain groups. The mixed effects model accounted for the correlation between the dominant and nondominant sides. We used Fisher exact test to compare the proportion of participants in the DH-pain and DH–no pain groups that showed clinical signs of anxiety (score on the HADS > 8). For all analyses, the alpha level was set at 0.05.

Results

Participants

Two-hundred thirteen individuals were invited to participate, 102 enrolled in the study, and 97 were included in the analysis (Fig. 2 and Table I). No DH students reported any shoulder injuries occurred during the study period (baseline to follow-up). One OT student reported sustaining a clavicle fracture on the nondominant arm 3 months before the follow-up evaluation. This participant did not report any shoulder pain at follow-up (VAS score $= 0$); therefore, this OT student was not excluded from the analyses.

Incidence of shoulder pain

At the end of the first academic year, 14 DH students (31.1%) developed pain (mean $\pm$ SD change in shoulder pain $= 38.8 \pm 19.4$ VAS score points) compared to 4 (7.7%) OT students ($P < .01$, relative risk $= 4.0$; Table II). DH students had a higher incidence of shoulder pain in both the dominant and nondominant shoulder, and 8 DH students developed pain concomitantly in the dominant and nondominant shoulder.

Longitudinal changes in supraspinatus tendon morphology and psychosocial outcomes

We did not find significant group-by-side interactions; therefore, results for bilateral outcomes (supraspinatus cross-sectional thickness, acromiohumeral distance, occupation ratio, and PENN score) are collapsed across the dominant and nondominant sides.

Within-group changes over time

At the end of the first year in the program, supraspinatus tendon thickness increased 0.7 mm in the DH-pain group ($P < .01$; Fig. 3 and Table III) and 0.2 mm in the DH–no pain group ($P < .01$), but decreased 0.2 mm in the OT group ($P < .01$). Acromiohumeral distance decreased 0.5 mm in the DH–no pain group ($P < .01$). The occupation ratio increased 4.5% in the DH-pain group ($P < .01$) and 4.9% in the DH–no pain group ($P < .01$), but decreased 2.5% in the OT group ($P < .01$). The PENN shoulder score decreased -3.3 points in the DH-pain group ($P < .01$). HADS anxiety subscale scores increased 3.3 points in the DH-pain group ($P < .01$), and the HADS depression subscale scores increased 2.3 points in the DH-pain ($P < .01$) and 1.3 points in the DH–no pain ($P < .01$) groups.

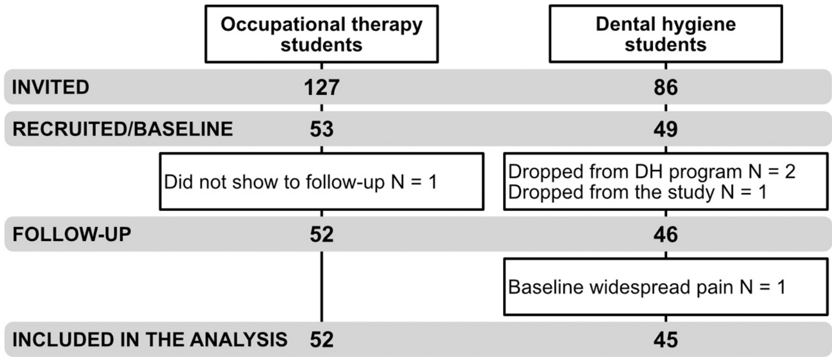

Figure 2 Flowchart of participants within the study. One DH student was excluded from the analysis because of widespread pain in the upper back, shoulder, and neck area.

Table I Demographic characteristics of the groups

Variable	DH students (n = 45)	OT students (n = 52)
Age, yr	24.9 ± 3.9	24.8 ± 2.4
Sex, female, n (%)	37 (82.2)	46 (88.5)
Height, m	1.63 ± 0.07	1.65 ± 0.08
Weight, kg	61.8 ± 12.2	64.1 ± 13.9
BMI	23.3 ± 3.8	23.3 ± 4.0
Handedness, n (%)		
Right	42 (93.3)	46 (88.5)
Left	2 (4.4)	4 (7.7)
Ambidextrous	1 (2.2)	2 (3.8)
Ethnicity, n (%)		
Hispanic or Latino	16 (35.6)	8 (15.4)
Not Hispanic or Latino	29 (64.4)	44 (84.6)
Race, n (%)		
American Indian	0 (0.0)	0 (0.0)
Asian	13 (28.9)	27 (51.9)
Native Hawaiian	1 (2.2)	0 (0.0)
Black	1 (2.2)	2 (3.8)
White	18 (40.0)	18 (34.6)
Other	12 (26.7)	5 (9.6)

BMI, body mass index; *DH*, dental hygiene; *OT*, occupational therapy.
Data are presented as mean ± SD unless otherwise indicated.

Between-group comparison of changes over time

At the end of the first year in the program, the supraspinatus tendon of the DH-pain group thickened 0.4 mm more than the DH–no pain group ($P < .01$; Fig. 3 and Table III) and 0.9 mm more than the OT group ($P < .01$). The supraspinatus tendon of the DH–no pain group thickened 0.4 mm more than the OT group ($P < .01$). We found a greater increase of occupation ratio in the DH-pain compared with the OT group (7.0%, $P < .01$), and the DH–no pain group compared to the OT group (7.4%, $P < .01$). PENN shoulder score decreased in the DH-pain group compared with both the DH–no pain (−3.3 points, $P < .01$) and the OT groups (−3.6 points, $P < .01$). The score on the HADS anxiety subscale increased in the DH-pain group compared with both the DH–no pain and OT groups (both −2.7 points, $P = .03$). The score on the HADS depression subscale increased in the DH-pain compared to the OT group (2.2 points, $P < .01$) and in the DH–no pain compared to the OT group (1.2 points, $P < .01$).

Clinical signs of tendinopathy or anxiety

At the end of the first year in the program, we found abnormal anxiety levels in 43% of the DH-pain group compared with only 15% of participants in the DH–no pain group (relative risk = 2.9, $P = .06$).

Discussion

Our findings show that young, healthy individuals newly exposed to repetitive sustained tasks with DH training have

Table II Proportions of participants developing shoulder pain at 1-year follow-up, defined by a change of 11 points from baseline to 1 year on the visual analog scale for pain

Groups	Developed pain		Relative risk (95% CI)	*P* value*
	Yes, n (%)	No, n (%)		
By subject irrespective of the side			4.0 (1.4, 11.4)	<.01
DH students	14 (31.1)†	31 (68.9)		
OT students	4 (7.7)†	48 (92.3)		
By shoulder, dominant side			3.9 (1.1, 13.1)	.03
DH students	10 (22.2)	35 (77.8)		
OT students	3 (5.8)	49 (94.2)		
By shoulder, nondominant side			6.9 (1.6, 29.3)	<.01
DH students	12 (26.7)	33 (73.3)		
OT students	2 (3.8)	50 (96.2)		

CI, confidence interval; *DH*, dental hygiene; *OT*, occupational therapy.
* Between-group comparison (Fisher exact test).
† Eight of 14 DH students reported onset of bilateral shoulder pain; 1 OT student reported bilateral shoulder pain.

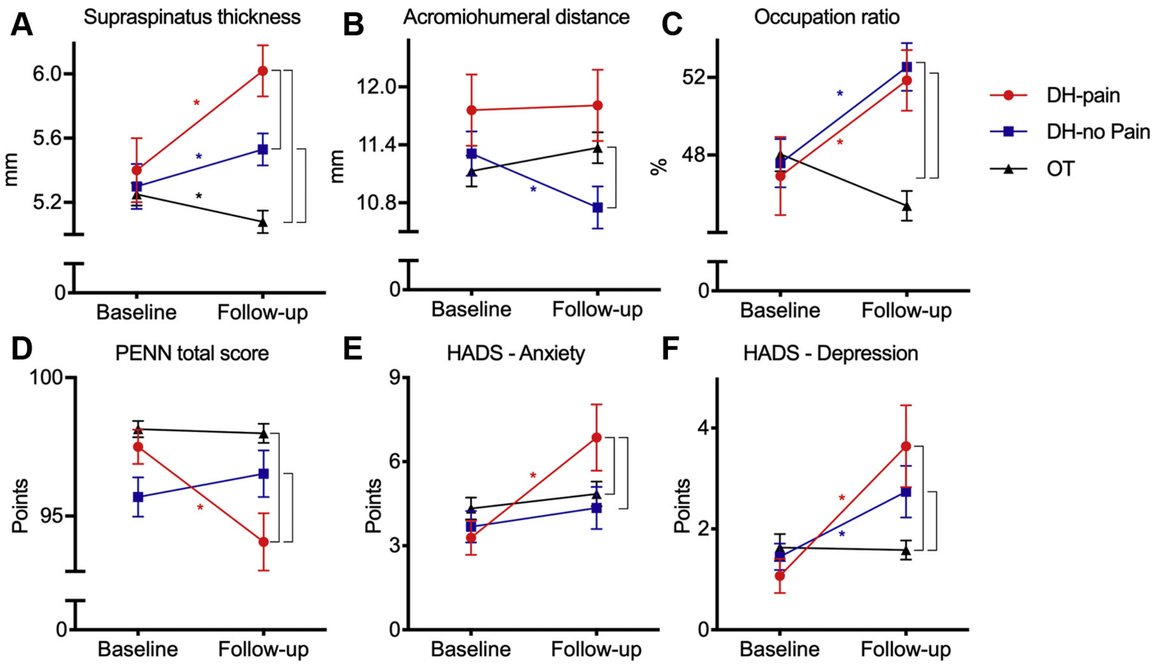

Figure 3 Effects of overload and pain on (**A**) supraspinatus cross-sectional thickness, (**B**) acromiohumeral distance, (**C**) occupation ratio, (**D**) the Pennsylvania shoulder score (PENN total score), and the Hospital Anxiety and Depression Scale (HADS) for (**E**) anxiety and (**F**) depression. We did not find significant group-by-side interactions; thus, data in panels **A**-**D** are collapsed between the dominant and nondominant arms. All data are presented as mean ± standard error of the mean. Baseline values of the supraspinatus cross-sectional thickness (panel **A**) are in line with normative data collected in young adults.[11] *Significant within-group change from baseline values ($P < .05$). Brackets indicate that changes from baseline were significantly different between groups ($P < .05$).

a 4-fold increased risk of developing shoulder pain. Our results align with epidemiologic studies that identified repetitive occupational demands as a risk factor for shoulder pain.[25] This study adds to the understanding of the mechanisms underlying the development of tendinopathy and the potential for concurrent contribution of anxiety to the theoretical models of tendinopathy.[6,7,16] In young, healthy individuals, stimulus-independent tendon-related pain is unlikely. The supraspinatus tendon of DH students thickened over time, and it thickened the most in those who developed shoulder pain, suggesting that repetitive load may be a mechanism of tendinopathy. In novice individuals exposed to repetitive shoulder tasks, there appears to be a direct relationship between the onset of shoulder pain and

Table III Adjusted within- and between-group mean difference for the change from baseline

	Within-group change from baseline			Between-groups difference for the change from baseline		
	DH-pain	DH–no pain	OT	DH-pain vs. DH–no pain	DH-pain vs. OT	DH–no pain vs. OT
Supraspinatus cross-sectional thickness, mm	0.7 (0.4, 0.9)*	0.2 (0.1, 0.4)*	−0.2 (−0.3, −0.1)*	0.4 (0.1, 0.8)*	0.9 (0.5, 1.2)*	0.4 (0.2, 0.7)*
Acromiohumeral distance, mm	0.3 (−0.3, 0.9)	−0.5 (−1.0, −0.1)*	0.2 (−0.2, 0.5)	0.9 (−0.1, 1.8)	0.2 (−0.7, 1.0)	−0.7 (−1.3, −0.1)
Occupation ratio, %	4.5 (1.5, 7.5)*	4.9 (2.9, 6.9)*	−2.5 (−4.1, −1.0)*	−0.4 (−4.7, 4.0)	7.0 (2.9, 11.1)*	7.4 (4.3, 10.5)*
PENN shoulder score, points	−3.3 (−5.4, −1.2)*	0.01 (−1.4, 1.4)	0.3 (−0.8, 1.4)*	−3.3 (−6.3, −0.3)*	−3.6 (−6.4, −0.8)*	−0.3 (−2.5, 1.9)
HADS anxiety subscale, points	3.3 (1.6, 5.1)*	0.6 (−0.6, 1.7)	0.7 (−0.3, 1.6)	2.7 (0.2, 5.3)*	2.7 (0.3, 5.0)*	−0.1 (−1.9, 1.7)
HADS depression subscale, points	2.3 (1.1, 3.4)*	1.3 (0.5, 2.0)*	0.04 (−0.6, 0.6)	1.0 (−0.6, 2.7)	2.2 (0.7, 3.8)*	1.2 (0.1, 2.4)*

MD, mean difference; *DH*, dental hygiene students; *OT*, occupational therapy students; *HADS*, Hospital Anxiety and Depression Scale.
Values are mean difference (95% confidence interval). Data are collapsed between sides for bilateral outcomes owing to the absence of group-by-side interactions ($P > .07$).
* $P < .05$.

tendon morphologic changes. This relationship is not apparent in the patellar and Achilles tendons of individuals previously exposed to repetitive loads, such as volleyball and basketball players.[12,20,21] It should be noted that despite the onset of shoulder pain, participants did not show clinically meaningful decline in shoulder function—measured with the PENN score—and were not actively seeking care for shoulder pain at follow-up. Thus, exposure period longer than approximately 1 year may be necessary to generate symptoms and tendon morphologic changes that require medical attention.

Changes in supraspinatus tendon morphology are associated with exposure to repetitive tasks and shoulder pain

The majority of participants in the DH-pain group (59%) had a change of tendon thickness greater than the measurement error (minimal detectable change = 0.3 mm), and 50% had a change greater than the accuracy limit (0.6 mm) of the ultrasonography machine for the tissue depth of the supraspinatus (Fig. 4). Our findings are consistent with studies reporting a 0.6 mm thicker supraspinatus tendon in those with painful tendinopathy compared with asymptomatic controls.[22,23] Tendon thickening appears to be a marker of tendon pathology, but thickening does not always

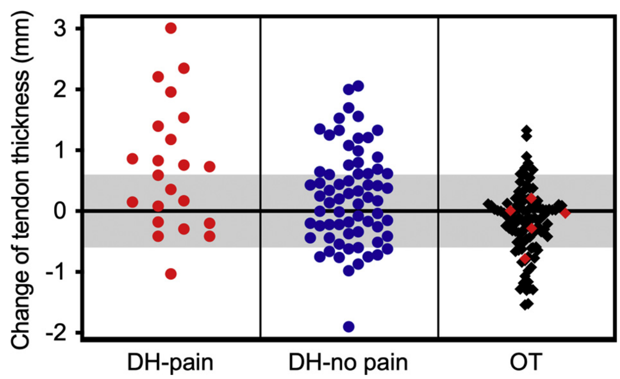

Figure 4 Individual change of supraspinatus tendon cross-sectional thickness from baseline. The DH-pain panel includes 22 data points (10 dominant and 12 nondominant); the DH–no pain panel includes 68 data points (35 dominant and 33 nondominant); the OT panel includes a total of 104 data points, with 5 in red corresponding to the tendons of the 3 dominant and 2 nondominant shoulders that developed pain. The shaded gray area corresponds to the limit of accuracy of the ultrasonography machine for the given tissue depth (0.6 mm). Supraspinatus tendons had an increase in thickness greater than the accuracy of the ultrasonography machine in 50% of the tendons in DH-pain, 32% of the tendons in the DH–no pain, and 8% of the tendons in the OT groups. This figure also supports the theory that tendons can change shape over time, as suggested by the tendons that had a decrease in thickness greater than the limit of accuracy of the ultrasonography machine (DH-pain, 5%; DH–no pain, 15%; OT, 20%).

Table IV Proportions of DH students with onset of shoulder pain that developed clinical signs of supraspinatus tendinopathy and anxiety at follow-up

	Developed shoulder pain		Relative risk (95% CI)	*P* value
	Yes, n (%)*	No, n (%)*		
Developed tendinopathy (n = 90 shoulders)†			1.9 (1.0, 3.6)	.22‡
Yes	10 (45.5)	16 (23.5)		
No	12 (54.5)	52 (76.5)		
Developed anxiety (n = 41 participants)§			2.9 (1.0, 8.6)	.06‖
Yes	6 (42.9)	4 (14.8)		
No	8 (57.1)	23 (85.2)		

DH, dental hygiene students; *CI*, confidence interval; *HADS*, Hospital Anxiety and Depression Scale.
The developed tendinopathy analysis considered each supraspinatus tendon separately (n = 90 shoulders). The developed anxiety analysis included only DH students without anxiety at baseline (n = 41).
* Percentages are calculated within column.
† Yes = supraspinatus tendon thickness change ≥0.8 mm.
‡ Between-group comparison with a mixed-model effect to account for the correlation between dominant and nondominant sides.
§ Yes = participants with HADS anxiety subscales score ≥8 points at follow-up.
‖ Between-group comparison with a Fisher exact test.

coincide with pain development, as demonstrated by the 23% of tendons that had thickening compatible with tendinopathy in the DH–no pain group (Table IV). An estimate of the minimum threshold at which the increase in supraspinatus thickness relates to the development of pain may be reflected by the mean difference of 0.4 mm between the DH-pain vs. DH–no pain group.

The supraspinatus tendon thickened 0.2 mm also in the DH–no pain group, but this change needs to be interpreted with caution because it is below the error threshold of the ultrasonography machine. We interpreted this change as a response to the shoulder repetitive tasks occurring with DH training, similar to the training effect observed in athletes and after an experimental shoulder loading protocol in pain-free tendons.[22] Asymptomatic volleyball players and baseball pitchers that primarily use their dominant arm for sports activity have a thicker supraspinatus tendon in the dominant than the nondominant shoulder.[19,31]

We found a 4.5% increase in occupation ratio in the DH-pain group at the end of the first year of training, but the increase is below the minimal detectible change. Although a thicker supraspinatus tendon occupies a greater portion of the subacromial space, compression may not be a predominant mechanism of shoulder pain at the onset of pain. Repetitive arm movements and sustained posture during DH training could exacerbate compression, as suggested by studies reporting a decrease of the subacromial space at 60° of arm elevation, increasing the risk of supraspinatus compression at lower arm elevation angles.[4,8,13] In rat models, subacromial compression and concurrent overload exacerbated maladaptive changes at the supraspinatus tendon.[29,30] Thus, compression may become a leading mechanism of supraspinatus tendinopathy at later stage of the condition. It should be noted that the occupation ratio also increased in the DH–no pain group, but the decrease in acromiohumeral distance with a concurrent increase in tendon thickness likely drove the occupation ratio increase in the DH–no pain group.

Onset of anxiety is present in DH participants who developed shoulder pain

At 1 year, we found an abnormal anxiety level (HADS anxiety score > 8 points) in 43% of participants in the DH group. Thus, anxiety may develop concurrently with shoulder pain. The average change in anxiety in the DH group (3.3 points) approached the minimal detectable change for the anxiety subscale of the HADS (3.8 points).[32] Anxiety and, more broadly, psychosocial distress have been consistently found in patients with chronic musculoskeletal pain compared to asymptomatic individuals. Our findings link pain sensation to the onset of maladaptive psychosocial responses, even in young and otherwise healthy individuals and in a relatively short time. These results support the theoretical presence of 2 potential mechanisms associated with the onset of shoulder pain: peripheral-structural and central.[17] These competing mechanisms for developing painful tendinopathy need further consideration to identify pain phenotypes of tendinopathy and enable personalized approaches to treatment. It is unlikely that anxiety may have developed in response to academic demands considering the absence of changes in the DH–no pain and OT groups. The results for the HADS-depression follow a similar trend but are likely not meaningful, given the small magnitude of change.

Limitations

Our sample population was predominantly female, which represents the dental hygienist population, but this limits the generalizability of this model to males. We did not track the individual training loads to control the effects of workload variation on shoulder pain development. These results are specific to DH students and may not generalize to other occupations with high shoulder-related workload demands. Although some structural features of tendinopathy are similar in tendons of the upper and lower extremities, these findings are specific to the supraspinatus tendon and may not generalize to other tendons (eg, Achilles or patellar tendons).

Conclusion

Our results provide support for the theoretical model of repetitive load as a mechanism of tendinopathy. The supraspinatus tendon thickens in the presence of repetitive shoulder tasks and thickens the most in those who develop shoulder pain. Concurrently, anxiety develops with shoulder pain, indicating the potential onset of maladaptive central psychosocial responses.

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Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2021.09.007.

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STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	N/A
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-7
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5-6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	11
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7-9
Bias	9	Describe any efforts to address potential sources of bias	9
Study size	10	Explain how the study size was arrived at	5-6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	9-10
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding (*b*) Describe any methods used to examine subgroups and interactions (*c*) Explain how missing data were addressed (*d*) If applicable, explain how loss to follow-up was addressed (*e*) Describe any sensitivity analyses	9-10
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (b) Give reasons for non-participation at each stage (c) Consider use of a flow diagram	11 Fig 1
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders (b) Indicate number of participants with missing data for each variable of interest (c) Summarise follow-up time (eg, average and total amount)	a) Table 1 b) None c) 6
Outcome data	15*	Report numbers of outcome events or summary measures over time	Table 2

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Table 2, 3, 4
		(*b*) Report category boundaries when continuous variables were categorized	Fig. 2, 3
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	Table 2, 4
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	N/A
Discussion			
Key results	18	Summarise key results with reference to study objectives	13-15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results	15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Title page

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.o