Arch Physioter 2025; 15: 97-109
ISSN 2057-0082 | DOI: 10.33393/aop.2025.3256
ORIGINAL RESEARCH ARTICLE

OPEN ACCESS

Differences in cervical mobility and pain sensitivity between patients with rotator cuff-related shoulder pain and asymptomatic subjects: a cross-sectional study

Néstor Requejo-Salinas[1,2], Rubén Fernández-Matías[3], Javier Gordo Herrera[1], Pablo Conesa López[1], Roy La Touche[1,4], Enrique Lluch-Girbés[5,6]

[1]Department of Physical Therapy, Superior Center for University Studies La Salle, Autonomous University of Madrid, Madrid - Spain
[2]International Doctoral School, Rey Juan Carlos University, Alcorcón - Spain
[3]Research Unit, Hospital Universitario Fundación Alcorcón, Alcorcón, Madrid - Spain
[4]Neuroscience and Craniofacial Pain Institute (INDCRAN), Madrid - Spain
[5]Department of Physical Therapy, University of Valencia, Valencian - Spain
[6]Pain in Motion Research Group, University of Valencia - Spain

ABSTRACT

Introduction: The cervical spine's role in shoulder pain remains unclear, particularly regarding its influence on shoulder pain severity and functional limitations. This study aimed to compare neck mobility, pain sensitivity, and strength between patients with rotator cuff-related shoulder pain (RCRSP) and asymptomatic controls and to explore associations between neck active range of motion (AROM) and shoulder outcomes.

Methods: A cross-sectional study was conducted with 50 patients with RCRSP and 50 asymptomatic controls. Neck AROM was measured with a CROM device, pressure pain thresholds (PPTs) with a digital algometer, and isometric neck strength with a handheld dynamometer. Shoulder pain and disability were assessed using the Visual Analog Scale (VAS) and the Shoulder Pain and Disability Index (SPADI).

Results: Compared to controls, patients with RCRSP exhibited reduced neck rotation toward the affected shoulder (mean difference: −5.19°; 95% CI: −8.84 to −1.38) and lower PPTs bilaterally (affected side: −1.49 kg/cm²; 95% CI: −1.99 to −1.00; unaffected side: −1.42 kg/cm²; 95% CI: −1.98 to −0.91). No differences were found in neck strength. Regression analysis showed that greater neck flexion, lateral flexion toward the affected side, and reduced protraction were associated with higher SPADI scores. Additionally, neck lateral flexion and rotation toward the affected side were negatively associated with shoulder pain intensity over the last week.

Conclusion: These findings suggest a potential interaction between the cervical spine and shoulder in RCRSP, underscoring the importance of a comprehensive assessment of both cervical and shoulder impairments in this condition.

Keywords: rotator cuff pain, neck, range of motion, pain threshold, muscle strength.

What is already known about this topic:

- *Previous research has suggested a relationship between the cervical spine and shoulder pain.*
- *Studies have reported alterations in the cervical region among individuals with shoulder pain compared to healthy controls. However, the specific nature of these impairments and their impact on shoulder function remain unclear due to limited research.*

What does the study add:

- *This cross-sectional study identifies a specific reduction in cervical rotation towards the affected shoulder and bilateral reductions in neck pain PPTs in patients with RCRSP, highlighting potential sensitization processes.*
- *Associations between specific cervical movements and shoulder outcomes, such as disability and pain intensity, provide new evidence of the interaction between cervical impairments and shoulder dysfunction.*
- *These findings underscore the importance of a comprehensive shoulder assessment that includes evaluating cervical spine impairments, which may contribute to shoulder dysfunction.*

Received: August 22, 2024
Accepted: March 24, 2025
Published online: May 12, 2025

This article includes supplementary material

Corresponding author:
Rubén Fernández-Matías
email: ruben.fernanmat@gmail.com

Introduction

Shoulder pain is a common complaint observed in the general population (1); the point prevalence of shoulder pain ranges from 6.9% to 26%, the 12-month prevalence from 4.7% to 55.2%, and the lifetime prevalence spans between 6.7% and 66.7% (1,2). Furthermore, shoulder pain results in high socioeconomic costs due to a significant decline in the patient's ability to work and perform activities of daily living (3,4).

Among shoulder musculoskeletal pain conditions, rotator cuff disorders are the most common, affecting a total of 6.8-22.4% of individuals over 40 years old (5-7). Various terms have been suggested to describe pain originating in the rotator cuff, including subacromial pain syndrome (8). Rotator cuff disease (9) or rotator cuff-related shoulder pain (RCRSP) (10). The latter refers to a clinical presentation of shoulder pain and impaired shoulder movement and function, typically experienced during abduction and external rotation movements (10). It encompasses a range of conditions, including subacromial pain (impingement) syndrome, rotator cuff tendinopathy, and symptomatic partial and full-thickness rotator cuff tears (10).

The cervical spine has been considered a contributing factor or even the main source of pain in people with shoulder pain, including people with RCRSP (11). From a biomechanical perspective, adequate cervicothoracic mobility is an important requirement for proper shoulder complex function (12,13), and restricted mobility has been proposed as a risk factor for shoulder pain (14-17). In line with this, the Regional Interdependence model proposes that impairments in one region of the body can influence the musculoskeletal and neuromuscular function and symptoms in other remote regions of the body (18,19). In addition, this model states that neurophysiological, biopsychosocial, and somatovisceral systems can also influence musculoskeletal function both locally and at remote sites (19).

Regarding the link between the cervical spine and shoulder, individuals with shoulder pain may present with restricted cervical range of motion (ROM) (15,20-22). For example, Rebelatto et al. found that individuals with RCRSP had decreased active neck extension compared to healthy controls (22). Limited cervical ROM has even been proposed as a potential risk factor for developing sports-related shoulder injuries(16). On the other hand, proper activation of cervical muscles has been suggested to be necessary for upper limb tasks (23). In line with this, some studies have found altered activity patterns in the cervical flexor muscles in patients with shoulder pain (24,25). However, no significant differences have been found in overall maximal isometric neck strength between people with RCRSP compared to healthy individuals (22), although evidence on this topic is currently scarce. Moreover, research has identified variations in neck pain sensitivity, measured by pressure pain thresholds (PPTs), in people with shoulder pain compared to asymptomatic subjects. Some studies have reported heightened pain sensitivity on the symptomatic side of the neck (26), while others observed increased sensitivity bilaterally (on both the symptomatic and contralateral side), suggesting a broader sensitization process (22,27). However, other studies reported opposite findings (28,29), thus making it difficult to draw firm conclusions in this regard.

Given the inconsistencies and variability in previous findings, this study aimed to address key limitations in previous research, such as small sample sizes, lack of adjustment for confounding factors like age and sex, and limited exploration of cervical-shoulder relationships. By using a larger sample, employing robust statistical methods, and analyzing associations between cervical impairments and shoulder outcomes in greater depth, this study sought to provide more comprehensive insights into these interactions.

Specifically, this research aimed to analyze potential differences in various cervical sensorimotor variables, including neck active range of motion (AROM), neck muscle strength, and neck PPTs, between patients with RCRSP and asymptomatic controls. Additionally, possible associations between neck AROM and shoulder pain and disability in the RCRSP group were investigated. It was hypothesized that individuals with RCRSP would exhibit reduced neck mobility, increased neck pain sensitivity (i.e., reduced neck PPTs), and lower levels of neck muscle strength as compared to asymptomatic controls. Furthermore, reduced neck AROM would be expected to be associated with increased shoulder pain and disability in people with RCRSP.

Materials and methods

This study adhered to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines (30) (Supplementary Material-1). Ethical approval was obtained from the Alcorcón Foundation Hospital Ethics Committee (HUFA) (Madrid, Spain). The study adhered to the Declaration of Helsinki principles (31).

Participants

Participants with RCRSP and asymptomatic individuals were recruited from three private physiotherapy clinics in the Community of Madrid (Spain). The recruitment period spanned from January 2022 to October 2023. Details of the study process can be found in Figure 1.

For the RCRSP group, inclusion criteria comprised: (i) subjects aged 18-65 years; (ii) unilateral shoulder pain lasting at least three months; (iii) pain reproduced during resisted muscle testing in shoulder abduction or external rotation that the participants identified as consistent with their usual shoulder pain (32); (iv) pain intensity ≥3 points on a Visual Analog Scale (VAS) and minimal or no pain at rest; and (v) familiar pain reproduced on at least three of the following five tests: Neer, Hawkins-Kennedy, Jobe, painful arc and external rotation resistance (33).

Exclusion criteria for the RCRSP group included: (i) neck pain within the last three months or a history of recurrent neck pain; (ii) history of prior shoulder surgery; (iii) signs or symptoms suggestive of radiculopathy, such as muscle weakness, hyporeflexia, or sensory changes; (iv) a positive Spurling or Arm Squeeze Test (34); (v) any systemic disease such as diabetes, fibromyalgia, rheumatoid arthritis, lupus, and/or neoplasms; (vi) shoulder pain of traumatic origin; (vii) passive shoulder external rotation ROM <45° or <50% compared to the contralateral shoulder, measured at 0° of shoulder abduction (35); (viii) positive sulcus sign for inferior instability and/or a positive drawer test and/or apprehension test for anterior and/or posterior instability (36); and (ix) current use of pain medication.

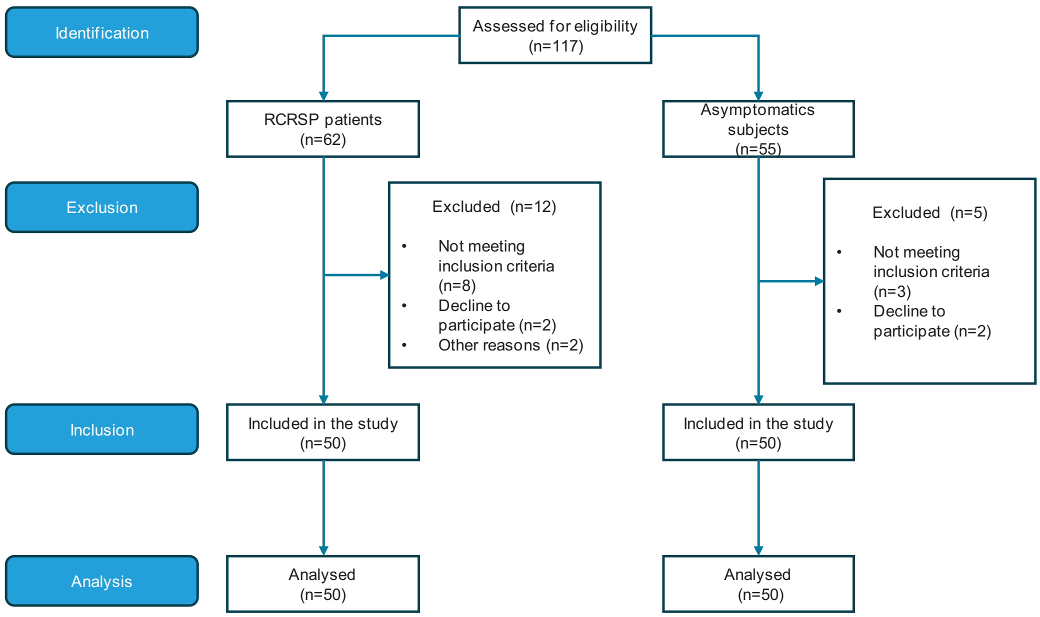

FIGURE 1 - Flow chart depicting the study process.

Asymptomatic controls were required to be aged 18-65 years. Exclusion criteria for this group included: (i) shoulder and/or neck pain in the last three months; (ii) neurological dysfunction of the upper limb; (iii) current use of pain medication; and (iv) previous history of shoulder surgery.

Sociodemographic data and psychological variables

Sociodemographic data, including sex, age, height, and weight, were recorded for each participant. In addition, psychological variables were also assessed to further characterize the study samples**.** Kinesiophobia was measured using the Tampa Scale of Kinesiophobia (TSK-11), which scores from 0 (less kinesiophobia) to 100 (more kinesiophobia) and has shown good reliability values (37). Catastrophizing levels were also measured using the Pain Catastrophizing Scale (PCS), which exhibits acceptable reliability values (38).

Shoulder outcomes

Pain intensity during the last week and current pain intensity were registered using a Visual Analog Scale (VAS). The VAS is presented as a 10-cm line anchored by verbal descriptors, usually “no pain” and “worst imaginable pain,” which has been demonstrated to be a reliable and valid pain measurement method (39). The minimal clinically important difference (MCID) for the VAS in people with rotator cuff disease is 1.37 cm (p = 0.0255) (40).

Shoulder disability was assessed using the Spanish-validated version of the Shoulder Pain and Disability Index (SPADI) (41). The SPADI is a self-administered questionnaire scoring from 0 (no disability) to 100 (maximum disability) (42). It has a reported test-retest reliability of 0.89-0.93 and a minimal detectable change (MDC95) of 12.2% (43).

Neck outcomes

Neck AROM was assessed using a CROM© device (Performance Attainment Associates, Roseville, MN; Fig. 2).

This device has demonstrated high intra- and inter-examiner reliability for measuring angular movements (ICC = 0.68-0.95; ICC = 0.79-0.99, respectively) and good validity (r = 0.93-0.98) (44). Furthermore, the CROM device has small measurement errors (SEMs ranging from 1.6° to 2.8° and MDCs ranging from 3.6° to 6.5°) (44). Additionally, the CROM© device allows us to measure the position of the head and its displacement in the sagittal plane from maximum protraction to maximum retraction, with excellent intra-rater reliability (ICC = 0.94-0.98), inter-rater reliability (ICC = 0.73-0.98) and an adequate validity [(r) = 0.47-0.78] (45). The following neck movements were assessed: flexion, extension, lateral flexion, rotation, protraction, and retraction. For each movement, three measurements were taken and averaged.

Maximal isometric neck strength was measured using a handheld dynamometer (MicroFET 2©, Hoggan Health Industries, West Jordan, UT, USA; Fig. 3), which has shown excellent intra- and inter-examiner reliability (ICC=0.73-0.95 and ICC = 0.78-0.86) (46-48), with a SEM of 0.59-0.87 Kgf (46) and a MDC of 1.62-4.85 in healthy patients (46, 47).

Maximal voluntary isometric contractions (MVICs) were assessed for neck flexion, extension, and lateral flexion. Participants performed three MVICs for each movement, each held for 5 seconds, with 30 seconds of rest between repetitions. Flexion strength was tested in a supine position, extension in a prone position, and lateral flexion in a side-lying position. The dynamometer was placed against the participant's forehead (flexion), occiput (extension), and temporal region (lateral flexion) to ensure standardized placement. Participants were instructed to generate maximal force against the device without compensatory movements, which were minimized using a

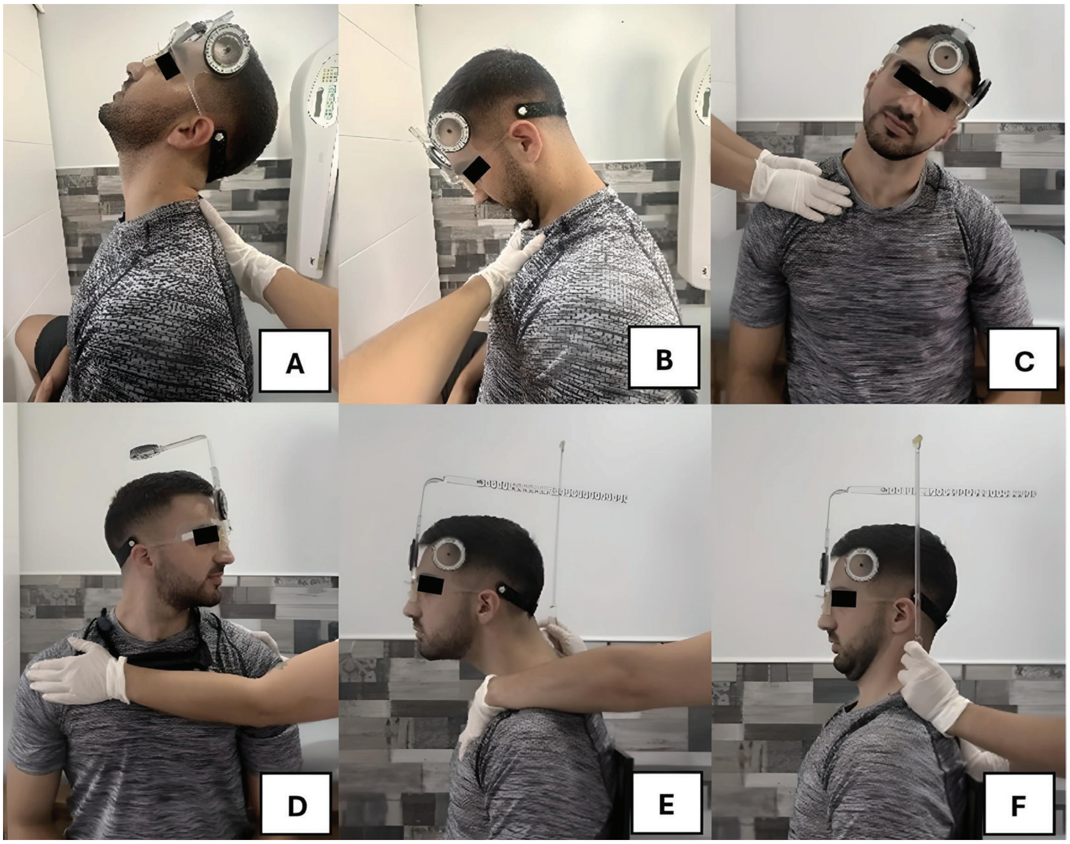

FIGURE 2 - Cervical AROM assessment. A: extension, B: flexion, C: lateral flexion, D: rotation, E: protraction, F: retraction.

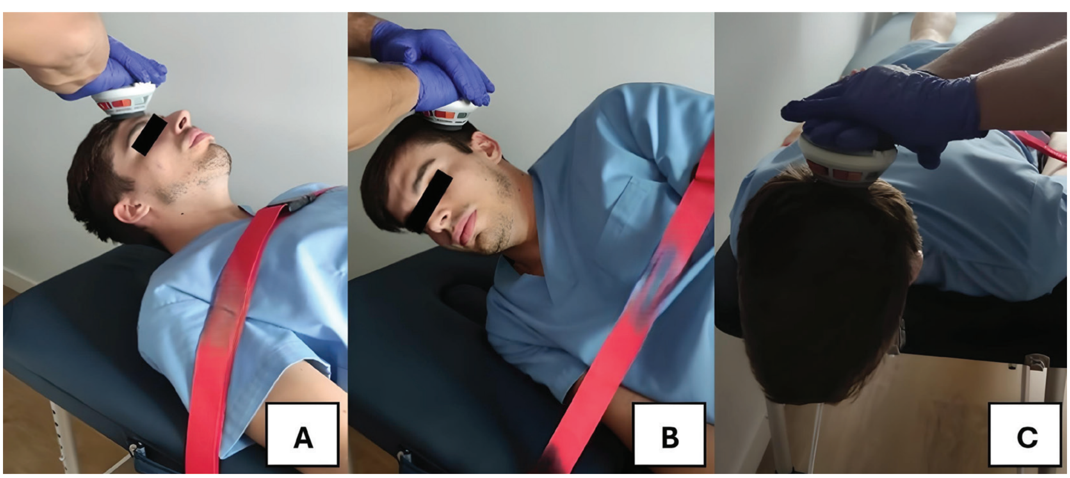

FIGURE 3 - Maximum isometric cervical strength assessment. A: flexion, B: lateral flexion, C: extension.

rigid strap secured at the T3 vertebra level. Verbal encouragement was provided to ensure maximum effort. The average of the three repetitions was used for analysis. An adjustable pillow was placed under the head during side-lying tests when necessary to maintain a neutral starting position (46).

Neck PPTs were assessed with a digital algometer Wagner FDX-25 (Wagner Instruments, Greenwich, CT) with a 1 cm^2 probe. Algometry is a reliable method for assessing neck PPTs, with high intra- and inter-examiner reliability (ICC = 0.97 and 0.73-0.91), an SEM of 0.18-0.64 kg/cm^2 (49,50) and an MDC of 0.43 kg/cm^2 (50) in asymptomatic individuals. The algometer was positioned perpendicularly to the participant's skin. Pressure was then gradually increased at a rate of approximately 0.5 kg/s until pressure was reported as painful. Three consecutive measurements were obtained with a 30-second rest period between repetitions. Neck PPTs were measured bilaterally on the C5-C6 zygapophyseal joints due to their segmental relationship with the shoulder (28).

The order of all measurements, including AROM, neck muscle strength, and PPTs, was randomized to minimize potential bias and ensure consistency across participants. All measurements were conducted by two trained assessors using standardized protocols.

In the asymptomatic group, all bilateral neck measurements (e.g., PPTs, AROM in rotation) were performed on one randomly selected side. As asymptomatic participants do not have a "symptomatic" or "non-symptomatic" side, this approach allowed meaningful comparisons with the corresponding sides in the symptomatic group while maintaining consistency in the analysis.

Sample size calculation

The sample size calculation was based on the expected width of the 95% confidence interval for the adjusted mean difference from a multivariable linear regression model in neck rotation for the covariates age, height, weight, and sex, with an assumed 80% power, following Kelley and Maxwell's proposal (51). Calculations were performed using the "ss.aipe.reg.coef" function in the R package 'MBESS' (Ken Kelley (2022). MBESS: The MBESS R Package. R package version 4.9.2).

A correlation of 0.30 was assumed between the covariates, and a biserial-point-biserial correlation coefficient value of 0.24 was assumed between the pain factor and the covariates. A biserial-point-biserial coefficient was also assumed between the pain factor and the dependent variable (neck rotation ROM) 0.24, as well as a correlation of 0.30 between the covariates and the dependent variable. Finally, a standard deviation of 7º for neck rotation ROM was estimated based on previous published literature (52). A total width of the 95% confidence interval of 6º (±3º accuracy) was considered acceptable. With these data, the necessary sample size was determined to be 99 subjects, which was rounded up to 100 (50 subjects with RCRSP and 50 asymptomatic controls) to maintain a 1:1 ratio in the pain factor.

Statistical analysis

All statistical analyses were conducted using the software R v.4.1.0 (R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria). The width of the confidence interval for all analyses was set a priori to 95%.

The intra-rater reliability of the measurement procedures was evaluated using an intraclass correlation coefficient with an absolute agreement ($ICC_{2,1}$) with the R package "irrICC."

For the descriptive analysis of quantitative variables, the mean, standard deviation (SD), median, first and third quartiles, and minimum and maximum values were reported. For categorical variables, the absolute frequencies and percentages were reported. Furthermore, the correlation matrix between all quantitative variables, histograms, and Q-Q plots was also reported, as well as measures of kurtosis and skewness, aiming to evaluate the distribution of the data.

For the analysis of between-group differences on outcome measures, an ordinary least squares regression was used to estimate adjusted between-group differences for age, sex, height, and weight, using the package "rms" (Harrell, 2022). A percentile bootstrap procedure with 5,000 samples was used to calculate 95% confidence intervals for each mean difference using the package "boot" (Canty and Ripley, 2022). This type of analysis is a better choice than the traditional t-test because it allows for the estimation of between-group differences, adjusting for the confounding effects of multiple covariates and providing a better understanding of the relationship between shoulder pain and the outcome measures. These adjusted between-group differences are interpreted as mean differences between shoulder pain and healthy subjects, assuming both groups have the same values in the covariates (i.e., eliminating their influence in the observed differences).

For the analysis of the relationship between cervical ROM measures (adjusted for age, sex, height, and weight) and shoulder disability measured with the SPADI as well as shoulder pain intensity during the last week, two beta regression models were conducted using the package "betareg" (53). These factors were adjusted due to their potential influence on cervical ROM (54-56). Beta regression was selected because this model can cope with bounded variables, which present with heteroskedasticity and usually have non-linear relationships with other variables. In addition, beta regression prevents the predicted values and the upper and lower bounds of the confidence intervals from falling outside the bounding limits of the outcome variable.

The effect size of the predictor variables was presented as the odds ratio for the outcome measure as per unit change in the predictor variable, with a value of 1 meaning no association, a value >1 meaning a positive association, and a value <1 meaning a negative association. In addition, diagnostic plots were also constructed for each model to evaluate their adequacy. Finally, plots of significant predictor values versus fitted values (with 95% percentile predictor intervals), holding all other predictors constant (and sex set to female), were also constructed to facilitate the interpretation of the significant relationships observed.

Results

The final sample was composed of 50 subjects with RCRSP (26 male) with a mean age of 41.1 (SD, 13.80) years, and a mean body mass index of 24.99 (SD, 3.28), and 50 healthy controls (26 male) with a mean age of 36.76 (SD, 13.36) years, and a mean body mass index of 25.23 (SD, 3.74) (Fig. 1). The characteristics of participants are presented in Table 1, and the full descriptive statistics, including median, quartiles, and measures of kurtosis and skewness, are presented in Supplementary Material 2. Furthermore, the normal Q-Q plots are presented in Supplementary Material 3, and the histograms in Supplementary Material 4.

The intra-rater reliability of the range of motion measurements was good for healthy subjects, with an $ICC_{2,1}$ value ranging from 0.838 to 0.968, and for pain subjects, with values ranging from 0.853 to 0.972. Regarding strength measurements, it was also good, with an $ICC_{2,1}$ value ranging from 0.973 to 0.981 for healthy subjects and from 0.97 to 0.982 for pain subjects. Finally, reliability was also good for PPT measurements, ranging from 0.91 to 0.93 for healthy subjects and from 0.916 to 0.944 for pain subjects.

TABLE 1 - Characteristics of participants

Variable	N	Mean	SD	Median	N	Mean	SD	Median
Group		**Healthy group**				**Shoulder pain group**		
Sex	50				50			
Male	26	52%			26	52%		
Female	24	48%			24	48%		
Age, years	50	36.76	13.36	34	50	41.1	13.80	41.5
Height, cm	50	170.6	9.465	170	50	169.98	9.55	169
Weight, kg	50	73.92	14.58	74.5	50	71.32	14.56	69.6
BMI, kg/m^2	50	25.23	3.74	25.2	36	24.99	3.28	25.55
Time with pain, days					50	469	647.76	182.5
Dominant side	50				50			
... Left	0	0%			7	14%		
... Right	50	100%			43	86%		
Affected side	0				50			
... Left					25	50%		
... Right					25	50%		
Previous shoulder pain (beyond the last three months)	50				50			
... No	45	90%			39	78%		
... Yes	5	10%			11	22%		
Previous neck pain (outside the last three months)	50				50			
... No	42	84%			35	70%		
... Yes	8	16%			15	30%		
Pain (actual)					50	3.95	2.55	3
Pain (last week)					50	4.85	1.86	4.2
SPADI (pain)					50	46.16	22.63	43
SPADI (disability)					50	26.8	21.9	24.38
SPADI (total)					50	32.738	19.36	32.31

Abbreviations: SD, standard deviation; BMI, body mass index; SPADI, Shoulder Pain and Disability Index.

Between-group differences in neck AROM

The descriptive statistics of all neck AROM outcome measures and the adjusted mean differences are presented in Table 2.

The adjusted analyses revealed a significant between-group difference in neck rotation, with the RCRSP group showing less neck rotation towards the affected shoulder (mean difference, −5.19°; 95% CI, −8.84° to −1.38°) compared to asymptomatic controls. There were no significant differences in the other neck AROM measures (Table 2).

Between-group differences in neck muscle strength

Regarding neck muscle strength, there were no significant adjusted mean between-group differences (Table 2).

Between-group differences in neck PPTs

The RCRSP group showed greater pain sensitivity in the cervical spine (i.e., lower neck PPTs) both in the side of the affected shoulder (mean difference, −1.49 kg/cm2; 95% CI, −1.99 to −1.00) and unaffected shoulder (mean difference, −1.42 kg/cm2; 95% CI, −1.98 to −0.91) compared to asymptomatic controls.

Relationship between neck AROM and shoulder pain and disability in the RCRSP group

The full model statistics and coefficients for each predictor are presented in Tables 3 and 4, and the diagnostic plots are presented in Supplementary Material 5.

TABLE 2 - Between-group differences

Variable	Healthy (n = 50), mean (SD)	Shoulder pain (n = 50), mean (SD)	Adjusted mean difference# (95% CI)£
Neck range of motion, degrees			
Neck protraction	5.50 (1.36)	4.94 (1.79)	-0.45 (-1.04 to 0.11)
Neck retraction	3.44 (0.99)	3.57 (1.13)	0.24 (-0.18 to 0.62)
Neck rotation (affected side)	71.74 (10.03)	64.95 (10.57)	-5.19 (-8.84 to -1.38) *
Neck rotation (unaffected side)		67.13 (11.52)	-2.90 (-6.50 to 1.01)
Neck lateral flexion (affected side)	41.03 (9.22)	40.60 (9.38)	1.13 (-1.83 to 4.34)
Neck lateral flexion (unaffected side)		39.89 (9.20)	-0.03 (-3.19 to 3.22)
Neck flexion	58.15 (10.80)	56.59 (11.53)	-0.97 (-5.16 to 3.09)
Neck extension	71.04 (12.51)	66.20 (15.53)	-2.81 (-7.83 to 1.91)
Neck strength, kgf			
Neck lateral flexion (affected side)	12.28 (5.90)	12.34 (6.41)	0.95 (-0.81 to 2.66)
Neck lateral flexion (unaffected side)		12.42 (6.75)	1.01 (-0.70 to 2.75)
Neck flexion	10.55 (5.66)	9.52 (5.56)	-0.08 (-1.66 to 1.41)
Neck extension	15.16 (6.23)	14.47 (6.83)	0.41 (-1.38 to 2.21)
Mechanosensitivity and psychological outcomes			
PPT (affected side), kg/cm^2	3.35 (1.63)	1.90 (1.01)	-1.49 (-1.99 to -1.00) *
PPT (unaffected side), kg/cm^2		1.97 (1.16)	-1.42 (-1.98 to -0.91) *
PCS	8.24 (9.66)	9.68 (9.06)	1.17 (-2.72 to 5.03)
TSK-11	19.14 (4.42)	23.42 (6.78)	3.80 (1.55 to 6.22) *

#Adjusted for age, height, weight, and sex. £Confidence intervals based on a percentile bootstrap procedure with 5,000 samples. Abbreviations: SD, standard deviation; CI, confidence interval; PPT, pressure pain threshold; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia. * $p < 0.05$

The evaluation of diagnostic statistics and plots of the first model, with the SPADI as the dependent variable, revealed two influential subjects (namely 2 and 28) with Cook's distance above 0.60. The estimated pseudo-R2 of this model was 0.36. The model was developed again without these two influential values, which improved the diagnostic plots (Supplementary Material 5) and revealed an increase in the pseudo-R2 value up to 0.47 (Table 3). This model showed a significant regression coefficient for age (OR per unit change = 1.03), meaning that for each increment in one unit of age, there is an estimated odds ratio of 1.03 for the expected increment in SPADI, neck flexion (OR per unit change = 1.03), neck protraction (OR per unit change = 0.85), and neck lateral flexion towards the side of the affected shoulder (OR per unit change = 1.04)

Since no relevant issues were identified in the examination of diagnostic plots (Supplementary Material 5), the full sample was used to develop a model for shoulder pain intensity during the last week. This model explained 33% of the variance in shoulder pain intensity during the last week, as measured by a pseudo-R2 value of 0.33. There were significant regression coefficients for age (OR per unit change = 1.02), weight (OR per unit change = 1.02), neck lateral flexion towards the affected shoulder (OR per unit change = 1.04), and neck rotation towards the affected shoulder (OR per unit change = 0.98) (Table 4).

The predicted value of SPADI and pain intensity as a function of the significant predictor parameters holding all other predictors constant at the mean are presented in Supplementary Material 6, aiming to improve the interpretation of the significant relationships observed.

Discussion

This observational study investigated differences in cervical sensorimotor variables between individuals with RCRSP and asymptomatic controls, including neck AROM, neck muscle strength, and neck PPTs. Potential associations between cervical AROM and shoulder pain and disability in individuals with RCRSP were also explored. Our results showed that people with RCRSP had a bilateral increase in pain sensitivity in the cervical region, as reflected by lower bilateral neck PPTs and reduced neck active rotation towards the affected shoulder compared to asymptomatic controls. Furthermore, significant associations were found between neck AROM in different directions (neck flexion, protraction, and lateral flexion toward the affected shoulder) and SPADI scores in the RCRSP group. Additionally, neck lateral flexion and rotation

TABLE 3 - Beta regression for Shoulder Pain and Disability Index

Parameter	Regression (B) coefficient (95% CI)	OR
Intercept	–5.04 (–11.72 to 1.63)	0.01
Age	0.03 (0.01 to 0.05) *	1.03
Weight	0.02 (–0.01 to 0.04)	1.02
Height	0.01 (–0.04 to 0.05)	1.01
Sex (male = 1)	0.66 (–0.05 to 1.38)	1.94
Neck flexion	0.03 (0.01 to 0.05) *	1.03
Neck extension	–0.001 (–0.02 to 0.02)	1.00
Neck protraction	–0.16 (–0.29 to -0.03) *	0.85
Neck retraction	–0.11 (–0.34 to 0.12)	0.90
Neck lateral flexion (affected side)	0.04 (0.01 to 0.07) *	1.04
Neck lateral flexion (unaffected side)	–0.013 (–0.05 to 0.03)	0.97
Neck rotation (affected side)	–0.03 (–0.06 to 0.003)	0.99
Neck rotation (unaffected side)	0.01 (–0.02 to 0.04)	1.01

Standardized weighted residuals 2:

Min	1Q	Median	3Q	Max
−2.04	−0.89	−0.04	0.91	2.54

Phi coefficient (precision model with identity link):

	Estimate	Std. Error	z value	95% CI
(phi)	11.94	2.38	5.03	7.29 to 16.60

Type of estimator: maximum likelihood
Log-likelihood: 34.4 on 14 degrees of freedom
Pseudo R-squared: 0.474

Abbreviations: CI, confidence interval; 1Q, first quartile; 3Q, third quartile. OR refers to the odds ratio for the outcome measure per unit change in the predictor variable. * $p < 0.05$

towards the affected shoulder were associated with self-reported pain intensity during the last week in this group.

Neck AROM

Our study revealed a significant decrease in neck rotation towards the affected shoulder among patients with RCRSP compared to asymptomatic controls. This finding seems to align with previous studies where limitations in cervical ROM were reported in individuals with shoulder pain (15,20,22). However, Rebelatto et al. found a substantial reduction in cervical extension AROM, but not rotation, in patients with RCRSP, compared to controls (22). These differences may be due to several various factors, including the methodology used to select the neck side for neck AROM assessment in healthy subjects (dominance matched to their symptomatic counterparts in Rebelatto et al. study versus random selection in our case), differing inclusion criteria such as the duration of symptoms (4 weeks vs. 3 months) or pain intensity levels for the RCRSP group.

Cervical radiculopathy/radicular pain might be a contributing factor to shoulder pain in some patients (57). Cervical rotation and extension can narrow the intervertebral foramina (58,59), so limitations in these movements in people with shoulder pain, including RCRSP, as reported in Rebelatto and colleagues' study and ours, might indicate a protective mechanism to prevent further nerve compression in the presence of a subclinical cervical nerve root problem. Indeed, limited cervical ipsilateral rotation has been included as a diagnostic criterion for cervical radiculopathy (60).

Alternatively, these restrictions in AROM might represent a motor adaptation or avoidance strategy resulting from pain, which is a common phenomenon in musculoskeletal conditions (61). Furthermore, psychological factors such as fear of movement (kinesiophobia) may also influence these findings. In our study, patients with RCRSP exhibited significantly higher levels of kinesiophobia compared to asymptomatic participants, as reflected by their TSK-11 scores (mean difference: 3.80; 95% CI: 1.55-6.22). This aligns with the fear-avoidance model, which proposes that pain-related fear can result in reduced mobility and activity (62). Moreover, previous research has shown that psychological factors, including kinesiophobia, can significantly affect joint range of motion in musculoskeletal pain conditions (63).

Neck muscle strength

Few studies have examined the role of impaired function of cervical muscles in people with shoulder pain (22,24,25). We did not find significant differences in neck muscle strength between individuals with RCRSP and asymptomatic subjects, which is in accordance with Rebelatto et al.'s findings (22). However, neither of the two studies assessed maximal

TABLE 4 - Beta regression for pain intensity within the last week

Parameter	Regression (B) coefficient (95% CI)	OR
Intercept	–0.18 (–6.43 to 6.07)	0.84
Age	0.02 (0.003 to 0.04) *	1.02
Weight	0.02 (0.001 to 0.05) *	1.02
Height	–0.02 (–0.06 to 0.02)	0.98
Sex (male = 1)	0.40 (–0.24 to 1.05)	1.50
Neck flexion	0.02 (–0.004 to 0.04)	1.02
Neck extension	0.01 (–0.01 to 0.02)	1.01
Neck protraction	0.001 (–0.13 to 0.13)	1.00
Neck retraction	0.10 (–0.10 to 0.29)	1.10
Neck lateral flexion (affected side)	0.04 (0.01 to 0.07) *	1.04
Neck lateral flexion (unaffected side)	–0.02 (–0.05 to 0.01)	0.97
Neck rotation (affected side)	–0.03 (–0.05 to -0.001) *	0.98
Neck rotation (unaffected side)	0.01 (–0.02 to 0.03)	1.01

Standardized weighted residuals 2:

Min	1Q	Median	3Q	Max
-2.33	-0.82	-0.12	0.77	2.13

Phi coefficient (precision model with identity link):

	Estimate	Std. Error	z value	95% CI
(phi)	9.95	1.90	5.23	6.22 to 13.68

Type of estimator: maximum likelihood
Log-likelihood: 25.39 on 14 degrees of freedom
Pseudo R-squared: 0.33

Abbreviations: CI, confidence interval; 1Q, first quartile; 3Q, third quartile. OR refers to the odds ratio for the outcome measure per unit change in the predictor variable. * $p < 0.05$

isometric rotational strength, which could be important considering the differences in neck rotation found in our study.

Beyond maximal isometric neck strength, evaluating the specific function of the deep cervical musculature in people with RCRSP may warrant further investigation. Some studies have suggested a potential link between the function of the deep cervical muscles and upper limb (23-25). Therefore, analyzing the function of the deep cervical muscles by means of tests such as the craniocervical flexion test or the deep neck flexors endurance test in people with RCRSP may offer a more comprehensive understanding of cervical muscle (dys) function in this population (64).

Neck PPTs

Studies examining neck PPTs in patients with shoulder pain have yielded inconsistent results (22,25-28). Similar to our study, Rebelatto et al. found decreased PPT values measured in the upper trapezius in patients with RCRSP compared to healthy controls on both affected and unaffected sides. However, we observed larger differences in PPT values between patients and asymptomatic controls (−1.41 kg/cm² vs. −0.4 kg/cm² on the affected side, −1.52 kg/cm² vs. −0.66 and 0.4 kg/cm² on the unaffected side). Furthermore, reduced PPTs have been identified bilaterally at the C5-C6 zygapophyseal joint in male wheelchair basketball players with unilateral shoulder pain compared to asymptomatic basketball players (with or without wheelchairs) (27). Another study by Hidalgo-Lozano et al. reported lower neck PPTs in the levator scapulae of subjects with Subacromial Impingement Syndrome (SIS) compared to healthy subjects (26). However, this study only included right-handed subjects with dominant side involvement, and measurements were taken solely on that side. Additionally, the study had a small sample size (10 healthy subjects and 12 patients with SIS).

Hidalgo-Lozano et al. also conducted a similar study comparing PPTs on the dominant side of the levator scapulae, upper trapezius, sternocleidomastoid, and anterior scalene muscles in elite swimmers with and without shoulder pain, as well as asymptomatic elite athletes (25). The results indicated reduced PPT levels in swimmers with shoulder pain compared to elite athletes across all muscles. However, no significant differences were found between elite swimmers with and without shoulder pain. Other studies have reported no significant differences in neck PPTs measured over the upper trapezius, levator scapulae, and articular pillar of the C5-C6 zygapophyseal joint when comparing the affected and unaffected sides of patients with SIS to the dominant side of healthy controls (28).

Several factors could contribute to the observed inconsistencies in neck PPT results in people with shoulder pain, including RCRSP, such as variations in inclusion criteria, sample size, measurement site (e.g., upper trapezius vs. C5-C6 zygapophyseal joints), or failure to adjust for potential confounders.

The bilateral increase in pain sensitivity observed within the cervical region of RCRSP patients in this study may reflect both peripheral and central sensitization processes (65). While the role of central nervous system sensitization in shoulder pain remains inconsistent (66), our findings of widespread mechanical hyperalgesia in the neck region suggest potential alterations in central pain processing among RCRSP patients. The inclusion of a remote PPT measurement (e.g., tibial anterior) may have provided a better opportunity to investigate the role of centrally-mediated mechanisms.

Hyperactivity of the upper trapezius muscle, which has been reported in patients with RCRSP (67), may also contribute to reduced PPTs in this population. Excessive activation of this muscle could lead to increased nociceptive input or myofascial pain syndromes, which are known to reduce pain pressure thresholds (68). Additionally, psychological factors, such as fear-avoidance beliefs and kinesiophobia, may further exacerbate pain sensitivity in this population (69).

Associations between neck AROM and shoulder pain and disability

The results suggest that neck mobility may be closely linked to shoulder function, reinforcing the concept of an interplay between these regions. Arm elevation requires adequate cervicothoracic mobility to ensure efficient scapular and shoulder mechanics (12,13). A lack of mobility in this region could impair the functionality of the rotator cuff and scapular muscles, potentially increasing the risk of shoulder dysfunction (15,70). However, given the modest strength of the associations observed, these results should be interpreted with caution.

Implications for clinical practice and future research

This study highlights the importance of evaluating the cervical spine in individuals diagnosed with RCRSP. The assessment of neck AROM may complement clinical evaluation when used alongside validated questionnaires for assessing shoulder pain and disability levels. Additionally, reduced cervical rotation towards the side of the shoulder with RCRSP may indicate a contribution of the cervical spine in the patient's symptoms (e.g., subclinical cervical nerve root problem). As no standardized protocols for assessing the cervical spine in patients with shoulder pain, including people with RCRSP are not available (71), future research should work on this aim.

Further research is needed to clarify the relationship between cervicothoracic mobility and shoulder pain and function. Longitudinal studies in initially asymptomatic populations, assessing cervical mobility prior to the onset of shoulder pain, could help determine whether cervical impairments are a cause or consequence of shoulder pain. Predictive models could also identify key factors, including cervicothoracic mobility, associated with the onset or persistence of shoulder pain. Interventional studies are warranted to evaluate the effects of improving cervicothoracic mobility on pain and functional outcomes in patients with RCRSP.

Moreover, investigating the role of cervical motor control and deep cervical musculature in RCRSP could provide valuable insights. As discussed earlier, targeted tests, such as the cranio-cervical flexion test and the deep neck flexor endurance test, may enhance our understanding of cervical muscle dysfunction and its impact on shoulder pain and function in this population.

Although the present study did not assess the interrelationships between cervical ROM, muscle strength, and pain sensitivity, this remains an important area for future research. Given the complexity of sensorimotor interactions in the cervical region, studies should explore how these variables influence one another and whether specific impairments contribute to overall dysfunction in individuals with RCRSP. Such investigations would require larger sample sizes and advanced statistical models, such as mediation or moderation analyses, to provide a more comprehensive understanding of these interactions.

Study limitations

Several limitations should be considered when interpreting the results of this study. First, assessors were not blinded to participants' pain status, potentially introducing bias and reducing the study's internal validity. Second, the levels of participants' physical activity were not assessed, which could have influenced the observed differences in PPTs (72). Third, the absence of a neck disability questionnaire (e.g., Neck Disability Index) may have led to the inclusion of asymptomatic individuals with functional limitations in the neck despite not reporting neck pain, potentially affecting the results (70). Additionally, although participants with shoulder or neck pain within the last three months were excluded, we cannot rule out the possibility of residual impairments in those with a remote history of pain. Future studies should consider incorporating objective assessments, such as imaging or functional tests, to confirm the absence of such impairments. Moreover, the generalizability of the study's results may be limited to populations with RCRSP and may not necessarily extend to other shoulder conditions, thus affecting external validity. Finally, the cross-sectional design precludes establishing causality, leaving open the question of whether our observations in the cervical spine represent a predisposing factor to shoulder pain, a consequence of the painful shoulder process, or an underlying cervical cause of shoulder pain.

Conclusion

This study investigated cervical variables in individuals with RCRSP, revealing differences in cervical AROM and PPTs compared to asymptomatic controls. The observed associations between cervical variables and shoulder pain and disability further support the concept of regional interdependence in people with shoulder pain. Our findings emphasize the need for a comprehensive approach to RCRSP assessment and management including potentially contributing factors from the cervical spine.

Acknowledgments

We gratefully acknowledge all participating patients involved in the study.

Disclosures

Conflict of interest: The authors declare no conflict of interest.

Financial support: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contributions: Conceptualization (NRS, RLT, RFM, ELG), data curation(RFM), formal analysis (RFM, NRS), investigation (NRS, JGH, PCL), methodology (NRS, RLT, RFM, JGH, PCL, ELG), project administration (ELG, NRS), resources (NRS, JGH, PCL), supervision (ELG, NRS), writing – original draft (NRS, JGH, PCL), writing – review & editing(NRS, RLT, RFM, JGH, PCL, ELG).

Data availability statement: All data generated or analyzed during this study are included in this published article and its supplementary information section.

References

1. Luime JJ, Koes BW, Hendriksen IJM, et al. Prevalence and incidence of shoulder pain in the general population; a systematic review. Scand J Rheumatol. 2004;33(2):73-81. CrossRef PubMed
2. Lucas J, van Doorn P, Hegedus E, et al. A systematic review of the global prevalence and incidence of shoulder pain. BMC Musculoskelet Disord. 2022;23(1):1073. CrossRef PubMed
3. Greenberg DL. Evaluation and treatment of shoulder pain. Med Clin North Am. 2014;98(3):487-504. CrossRef PubMed
4. Linaker CH, Walker-Bone K. Shoulder disorders and occupation. Best Pract Res Clin Rheumatol. 2015;29(3):405-423. CrossRef PubMed
5. Kuhn JE. Prevalence, natural history, and nonoperative treatment of rotator cuff disease. Oper Tech Sports Med. 2023;31(1):150978. CrossRef
6. Littlewood C, May S, Walters S. Epidemiology of rotator cuff tendinopathy: a systematic review. Shoulder Elbow. 2013;5(4):256-265. CrossRef
7. Yamamoto A, Takagishi K, Osawa T, et al. Prevalence and risk factors of a rotator cuff tear in the general population. J Shoulder Elbow Surg. 2010;19(1):116-120. CrossRef PubMed
8. Diercks R, Bron C, Dorrestijn O, et al. Dutch Orthopaedic Association. Guideline for diagnosis and treatment of subacromial pain syndrome: a multidisciplinary review by the Dutch Orthopaedic Association. Acta Orthop. 2014;85(3):314-322. CrossRef PubMed
9. Zadro JR, O'Keeffe M, Ferreira GE, et al. Diagnostic labels for rotator cuff disease can increase people's perceived need for shoulder surgery: an online randomized controlled trial. J Orthop Sports Phys Ther. 2021;51(8):401-411. CrossRef PubMed
10. Lewis J, McCreesh K, Roy JS, et al. Rotator cuff tendinopathy: navigating the diagnosis-management conundrum. J Orthop Sports Phys Ther. 2015;45(11):923-937. CrossRef PubMed
11. Katsuura Y, Bruce J, Taylor S, et al. Overlapping, masquerading, and causative cervical spine and shoulder pathology: a systematic review. Global Spine J. 2020;10(2):195-208. CrossRef PubMed
12. Crosbie J, Kilbreath SL, Hollmann L, et al. Scapulohumeral rhythm and associated spinal motion. Clin Biomech (Bristol, Avon). 2008;23(2):184-192. CrossRef PubMed
13. Roren A, Nguyen C, Zauderer J, et al. Arm elevation involves cervical spine 3-D rotations. Ann Phys Rehabil Med. 2020;63(4):372-375. CrossRef PubMed
14. Norlander S, Aste-Norlander U, Nordgren B, et al. Mobility in the cervico-thoracic motion segment: an indicative factor of musculo-skeletal neck-shoulder pain. Scand J Rehabil Med. 1996;28(4):183-192. Accessed April 7, 2016. CrossRef PubMed
15. Norlander S, Gustavsson BA, Lindell J, et al. Reduced mobility in the cervico-thoracic motion segment--a risk factor for musculoskeletal neck-shoulder pain: a two-year prospective follow-up study. Scand J Rehabil Med. 1997;29(3):167-174. PubMed
16. Devaney LL, Denegar CR, Thigpen CA, et al. Preseason neck mobility is associated with throwing-related shoulder and elbow injuries, pain, and disability in college baseball pitchers. Orthop J Sports Med. 2020;8(5):2325967120920556. CrossRef PubMed
17. Bullock GS, Thigpen CA, Zhao H, et al. Neck range of motion prognostic factors in association with shoulder and elbow injuries in professional baseball pitchers. J Shoulder Elbow Surg. 2025;34(2):421-429. CrossRef PubMed
18. Wainner RS, Whitman JM, Cleland JA, et al. Regional interdependence: a musculoskeletal examination model whose time has come. J Orthop Sports Phys Ther. 2007;37(11):658-660. CrossRef PubMed
19. Sueki DG, Cleland JA, Wainner RS. A regional interdependence model of musculoskeletal dysfunction: research, mechanisms, and clinical implications. J Man Manip Ther. 2013;21(2):90-102. CrossRef PubMed
20. Medeni OC, Camci E, Duzgun I. The effect of active cervical lateral flexion range on shoulder joint range of motion in adhesive capsulitis patients: a pilot study. Ann Rheum Dis. 2013;72(suppl 3):A1097-A1097. CrossRef
21. Weh L, Ehlers K. Rotator syndrome of the shoulder and mobility of the cervical spine. Z Rheumatol. 1989;48(5):223-228. PubMed
22. Rebelatto MN, Alburquerque-Sendín F, Gava V, et al. Cervical sensitivity, range of motion and strength in individuals with shoulder pain: a cross-sectional case control study. Musculoskelet Sci Pract. 2023;67:102834.CrossRef PubMed
23. Gurfinkel VS, Lipshits MI, Lestienne FG. Anticipatory neck muscle activity associated with rapid arm movements. Neurosci Lett. 1988;94(1-2):104-108. CrossRef PubMed
24. Asker M, Ravnanger J, Bjørnstad T, Skillgate E. Correlation between neck motor control impairment and shoulder pain in elite male handball players. J Sci Med Sport. 2014;18:e76. CrossRef
25. Hidalgo-Lozano A, Calderón-Soto C, Domingo-Camara A, et al. Elite swimmers with unilateral shoulder pain demonstrate altered pattern of cervical muscle activation during a functional upper-limb task. J Orthop Sports Phys Ther. 2012;42(6):552-558. CrossRef PubMed
26. Hidalgo-Lozano A, Fernández-de-las-Peñas C, Alonso-Blanco C, et al. Muscle trigger points and pressure pain hyperalgesia in the shoulder muscles in patients with unilateral shoulder impingement: a blinded, controlled study. Exp Brain Res. 2010;202(4):915-925. CrossRef PubMed
27. Ortega-Santiago R, González-Aguado ÁJ, Fernández-de-Las-Peñas C, et al. Pressure pain hypersensitivity and referred pain from muscle trigger points in elite male wheelchair basketball players. Braz J Phys Ther. 2020;24(4):333-341. CrossRef PubMed
28. Alburquerque-Sendín F, Camargo PR, Vieira A, et al. Bilateral myofascial trigger points and pressure pain thresholds in the shoulder muscles in patients with unilateral shoulder impingement syndrome: a blinded, controlled study. Clin J Pain. 2013;29(6):478-486. CrossRef PubMed

29. Coronado RA, Kindler LL, Valencia C, et al. Thermal and pressure pain sensitivity in patients with unilateral shoulder pain: comparison of involved and uninvolved sides. J Orthop Sports Phys Ther. 2011;41(3):165-173.CrossRef PubMed
30. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol. 2008;61(4):344-349.CrossRef PubMed
31. General Assembly of the World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. J Am Coll Dent. 2014;81(3):14-18. PubMed
32. Requejo-Salinas N, Lewis J, Michener LA, et al. International physical therapists consensus on clinical descriptors for diagnosing rotator cuff related shoulder pain: A Delphi study. Braz J Phys Ther. 2022;26(2):100395. CrossRef PubMed
33. Michener LA, Walsworth MK, Doukas WC, et al. Reliability and diagnostic accuracy of 5 physical examination tests and combination of tests for subacromial impingement. Arch Phys Med Rehabil. 2009;90(11):1898-1903. CrossRef PubMed
34. Thoomes EJ, van Geest S, van der Windt DA, et al. Value of physical tests in diagnosing cervical radiculopathy: a systematic review. Spine J. 2018;18(1):179-189. CrossRef PubMed
35. Hanchard NCA, Goodchild L, Thompson J, et al. Evidence-based clinical guidelines for the diagnosis, assessment and physiotherapy management of contracted (frozen) shoulder: quick reference summary. Physiotherapy. 2012;98(2):117-120. CrossRef PubMed
36. Warby SA, Ford JJ, Hahne AJ, et al. Effect of exercise-based management on multidirectional instability of the glenohumeral joint: a pilot randomized controlled trial protocol. BMJ Open. 2016;6(9):e013083. CrossRef PubMed
37. Gómez-Pérez L, López-Martínez AE, Ruiz-Párraga GT. Psychometric properties of the Spanish version of the Tampa Scale for Kinesiophobia (TSK). J Pain. 2011;12(4):425-435. CrossRef PubMed
38. García Campayo J, Rodero B, Alda M, et al. Validation of the Spanish version of the Pain Catastrophizing Scale in fibromyalgia. Med Clin (Barc). 2008;131(13):487-492. CrossRef PubMed
39. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. J Clin Nurs. 2005;14(7):798-804. CrossRef PubMed
40. 40. Tashjian RZ, Deloach J, Porucznik CA, et al. Minimal clinically important differences (MCID) and patient acceptable symptomatic state (PASS) for visual analog scales (VAS) measuring pain in patients treated for rotator cuff disease. J Shoulder Elbow Surg. 2009;18(6):927-932. CrossRef PubMed
41. Membrilla-Mesa MD, Cuesta-Vargas AI, Pozuelo-Calvo R, et al. Shoulder pain and disability index: cross cultural validation and evaluation of psychometric properties of the Spanish version. Health Qual Life Outcomes. 2015;13(1):200. CrossRef PubMed
42. Roach KE, Budiman-Mak E, Songsiridej N, et al. Development of a shoulder pain and disability index. Arthritis Care Res. 1991;4(4):143-149.CrossRef PubMed
43. Membrilla-Mesa MD, Cuesta-Vargas AI, Pozuelo-Calvo R, et al. Shoulder pain and disability index: cross cultural validation and evaluation of psychometric properties of the Spanish version. Health Qual Life Outcomes. 2015;13:200. CrossRef
44. Audette I, Dumas JP, Côté JN, et al. Validity and between-day reliability of the cervical range of motion (CROM) device. J Orthop Sports Phys Ther. 2010;40(5):318-323. CrossRef PubMed
45. Elizagaray-García I, Obispo-Villamayor Á, Prats-Martínez C, et al. Measurement proprieties of the CROM instrument for assessing head posture, neck retraction and protraction. Musculoskelet Sci Pract. 2024;71:102950. CrossRef PubMed
46. Carnevalli APO, Bevilaqua-Grossi D, Oliveira AIS, et al. Intrarater and inter-rater reliability of maximal voluntary neck muscle strength assessment using a handheld dynamometer in women with headache and healthy women. J Manipulative Physiol Ther. 2018;41(7):621-627. CrossRef PubMed
47. Krause DA, Hansen KA, Hastreiter MJ, et al. A comparison of various cervical muscle strength testing methods using a handheld dynamometer. Sports Health. 2019;11(1):59-63. CrossRef PubMed
48. Vannebo KT, Iversen VM, Fimland MS, et al. Test-retest reliability of a handheld dynamometer for measurement of isometric cervical muscle strength. J Back Musculoskelet Rehabil. 2018;31(3):557-565. CrossRef PubMed
49. Chesterton LS, Sim J, Wright CC, et al. Interrater reliability of algometry in measuring pressure pain thresholds in healthy humans, using multiple raters. Clin J Pain. 2007;23(9):760-766. CrossRef PubMed
50. Walton DM, Macdermid JC, Nielson W, et al. Reliability, standard error, and minimum detectable change of clinical pressure pain threshold testing in people with and without acute neck pain. J Orthop Sports Phys Ther. 2011;41(9):644-650. CrossRef PubMed
51. Kelley K, Maxwell SE. Sample size for multiple regression: obtaining regression coefficients that are accurate, not simply significant. Psychol Methods. 2003;8(3):305-321. CrossRef PubMed
52. Ferrario VF, Sforza C, Serrao G, et al. Active range of motion of the head and cervical spine: a three-dimensional investigation in healthy young adults. J Orthop Res. 2002;20(1):122-129. CrossRef PubMed
53. Cribari-Neto F, Zeileis A. Beta regression in R. J Stat Softw. 2010;34(2):1-24. CrossRef
54. Kocur P, Tomczak M, Wiernicka M, et al. Relationship between age, BMI, head posture and superficial neck muscle stiffness and elasticity in adult women. Sci Rep. 2019;9(1):8515. CrossRef PubMed
55. Allen WE, Lin JJ, Barfield WB, et al. Shoulder motion decreases as body mass increases in patients with asymptomatic shoulders. JSES Int. 2020;4(3):438-442. CrossRef PubMed
56. Pan F, Arshad R, Zander T, et al. The effect of age and sex on the cervical range of motion – a systematic review and meta-analysis. J Biomech. 2018;75:13-27. CrossRef PubMed
57. Mimori K, Muneta T, Komori H, et al. Relation between the painful shoulder and the cervical spine with narrow canal in patients without obvious radiculopathy. J Shoulder Elbow Surg. 1999;8(4):303-306. CrossRef PubMed
58. Kitagawa T, Fujiwara A, Kobayashi N, et al. Morphologic changes in the cervical neural foramen due to flexion and extension: in vivo imaging study. Spine. 2004;29(24):2821-2825. CrossRef PubMed
59. Chang V, Basheer A, Baumer T, et al. Dynamic measurements of cervical neural foramina during neck movements in asymptomatic young volunteers. Surg Radiol Anat. 2017;39(10):1069-1078. CrossRef PubMed
60. Wainner RS, Fritz JM, Irrgang JJ, et al. Reliability and diagnostic accuracy of the clinical examination and patient self-report measures for cervical radiculopathy. Spine. 2003;28(1):52-62. CrossRef PubMed
61. Merkle SL, Sluka KA, Frey-Law LA. The interaction between pain and movement. J Hand Ther. 2020;33(1):60-66. CrossRef PubMed

62. Vlaeyen JWS, Kole-Snijders AMJ, Boeren RGB, et al. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. Pain. 1995;62(3):363-372. CrossRef PubMed
63. Özden F, Tuğay N, Karaman ÖN, et al. The relationship of fear of movement with pain, range of motion and function in patients with shoulder pathologies. Bull Fac Phys Ther 2021 261. 2021;26(1):1-5. CrossRef
64. Martins F, Bento A, Silva AG. Within-session and between-session reliability, construct validity, and comparison between individuals with and without neck pain of four neck muscle tests. PM R. 2018;10(2):183-193. CrossRef PubMed
65. den Boer C, Terluin B, van der Wouden JC, et al. Tests for central sensitization in general practice: a Delphi study. BMC Fam Pract. 2021;22(1):206. CrossRef PubMed
66. Noten S, Struyf F, Lluch E, et al. Central pain processing in patients with shoulder pain: a review of the literature. Pain Pract. 2017;17(2):267-280. CrossRef PubMed
67. Houry M, Bonnard M, Tourny C, et al. Kinematic, electromyographic and isokinetic measurements for the management of shoulder subacromial pain syndrome: A systematic review. Clin Biomech. 2023;107:106029. CrossRef
68. Wytrążek M, Huber J, Lipiec J, et al. Evaluation of palpation, pressure algometry, and electromyography for monitoring trigger points in young participants. J Manipulative Physiol Ther. 2015;38(3):232-243. CrossRef PubMed
69. Valenza-Peña G, Martín-Núñez J, Heredia-Ciuró A, et al. Relationship between pain intensity, physical factors, pronociceptive pain modulation profile and psychological vulnerability on upper limb disability in older patients with chronic shoulder pain. Int J Environ Res Public Health. 2022;19(22):15006. CrossRef PubMed
70. Libardoni TC, Armijo-Olivo S, Bevilaqua-Grossi D, et al. Relationship between intensity of neck pain and disability and shoulder pain and disability in individuals with subacromial impingement symptoms: a cross-sectional study. J Manipulative Physiol Ther. 2020;43(7):691-699. CrossRef PubMed
71. Walker T, Salt E, Lynch G, et al. Screening of the cervical spine in subacromial shoulder pain: a systematic review. Shoulder Elbow. 2019;11(4):305-315. CrossRef PubMed
72. Tesarz J, Schuster AK, Hartmann M, et al. Pain perception in athletes compared to normally active controls: a systematic review with meta-analysis. Pain. 2012;153(6):1253-1262. CrossRef PubMed