Muscle Activity Ratios of Scapular Stabilizers During Closed Kinetic Chain Exercises in Healthy Shoulders: A Systematic Review

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Context: Selective strengthening of scapular stabilizers is one of the emphases of the recent literature. Closed kinetic chain (CKC) exercises are used extensively in shoulder rehabilitation. However, a limited number of studies have reported scapular muscle ratios during CKC exercises. **Objectives:** To determine the CKC exercises producing the optimal ratios of the scapular stabilizer muscles in healthy shoulders. **Evidence Acquisition:** A systematic search within PubMed, Embase, CINAHL Plus, and SPORTDiscus with Full Text and ULAKBIM National Medical Database was performed up to January 2018. Studies were selected according to the predetermined criteria. If the pooled mean ratios (upper trapezius [UT]/middle trapezius [MT], UT/lower trapezius [LT], and UT/serratus anterior [SA]), which were calculated from the percentage of maximum voluntary contractions of muscles, were <0.60 , these exercises were considered as ideal for higher activation of the MT, LT, and SA than the UT. **Evidence Synthesis:** The search identified 1284 studies, and 29 observational studies were included for review. Seventy-nine CKC exercises were determined. Four exercises for the MT, 9 for the LT, and 59 for the SA were identified from the articles as being optimal exercises to activate the specified muscle more than the UT. **Conclusions:** This review identified optimal CKC exercises that provide good ratios between the MT, LT, and SA with the UT. Most exercises have optimal UT/SA ratios, but some exercises performed on unstable surfaces may lead to excessive activation of the UT relative to the SA. For the UT/MT, the isometric low row, inferior glide, and half supine pull-up with slings are the ideal exercises. Isometric one-hand knee push-up variations seem to be the best choice for the UT/LT. The results suggest that many CKC exercises may be utilized to enhance scapular muscle balance when rehabilitating shoulder pathology.

Keywords: electromyography, exercise therapy, subacromial impingement syndrome

Context

During movements of the shoulder, the scapula moves in coordination with the humerus.^{1,2} Serratus anterior (SA) with the upper (UT), middle (MT), and lower (LT) parts of the trapezius muscle work together in controlling normal scapular motion and providing stabilization.³ Specifically, excessive activation of the UT together with decreased activation of the LT, MT, and SA have been reported in patients with impingement syndrome⁴⁻⁶ and may contribute to the progress of impingement by altering scapular motion.⁵ Thereby, instead of global strengthening of the scapular muscles, restoration of the scapular muscle balance via the selective activation of the weaker muscles together with the minimal activation of the UT has been recommended for the rehabilitation of shoulder function.^{4,6,7}

Closed kinetic chain (CKC) exercises are exercises where the distal segment is fixed and more proximal segments are free to move.⁸ These exercises are critical in rehabilitation as they promote muscular balance, coordination, and proprioception, which are all the critical components of early rehabilitation programs.⁹ They can also be progressed to mimic sports functions and may better prepare athletes for return to sport.¹⁰ The effects are thought to be produced

by reproducing the normal physiologic coactivations of the agonist/antagonist muscles, thereby enhancing joint stability and providing normal motion patterns with minimal stress on the joints.^{10,11}

Electromyography (EMG) allows the measurement of the muscle activity, and EMG studies are frequently used to guide rehabilitation programs designed for musculoskeletal injuries.^{12,13} Most CKC exercises, especially those involving push, generally reveal high SA activity, and thus may be recommended to restore muscle balance and shoulder function.¹⁴⁻¹⁷ However, the high activation of the SA may not be appropriate if the UT activation remains high during the given exercise, as muscle balance may not be restored and scapulohumeral function may not be improved.^{6,7} It is imperative to know this ratio to better decide whether a certain exercise should be prescribed or not.⁷ Moreover, despite their frequent use, pushing exercises are not the only form of shoulder CKC exercises^{8,11} and relative activity of the SA (and also the MT and LT) to the UT is not comprehensively known. Scapular muscle ratios during open kinetic chain exercises have been previously studied and identified,¹³ but they have not been identified for CKC exercises.

Objectives

Therefore, the aim of this study was to identify CKC exercises that produce optimal muscle ratios of the scapular stabilizers in healthy shoulders. We believe that analyzing the extent to which shoulder CKC exercises promote optimal muscle ratios will be helpful for physiotherapists and other health professionals in the selection of appropriate exercises for selective muscle strengthening and restoration of scapular muscle balance.

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Evidence Acquisition

Search Strategy

A computerized, systematic search was conducted in January 2018 in the following databases: PubMed, Embase, CINAHL Plus with Full Text (EBSCO), SPORTDiscus with Full Text (EBSCO), and ULAKBIM National Medical Database. Terms were searched under 3 concepts: exercise, muscle (trapezius and SA), and EMG, and they were modified according to the specifications of each database (Appendix 1). The search was limited to studies published in English or Turkish and conducted in humans. However, there was no restriction for study type and publication date. One reviewer (Y.E.) imported all potentially relevant citations into EndNote reference management software (version X8.2; Thomson Reuters, New York, NY) and identified and removed duplicates. In addition, reference lists of studies included in full-text screening and were manually reviewed to identify additional studies.

Study Selection

Two reviewers (D.K. and Y.E.) independently performed an eligibility assessment using a prepiloted standardized form. First, the selection criteria were applied to the titles and abstracts. Then, full texts of all possible eligible studies were screened for inclusion in the review. A third reviewer (D.Ö.K.) was consulted in case of disagreement.

Eligibility Criteria

Studies were included if they were published as a full-text article in a peer-reviewed journal in English or Turkish, and included a group of participants with asymptomatic/healthy shoulders. To reduce the possible effects of shoulder pathology associated with aging, only studies involving participants with a mean age between 18 and 40 years were included.¹⁸

In line with the aim of the study, studies were required to use EMG as a primary tool to assess muscle activity of the UT with at least one of the following muscles: MT, LT, or SA. Only studies that reported the percentage of maximum voluntary isometric contraction (%MVIC), the percentage maximum voluntary contraction, and/or the muscle ratios were included to provide standardization. For the reproducibility, comparability, and quality analysis purposes, studies were included if they described the detailed methods of EMG analysis and normalization procedure, including those stating the guidelines followed. All included studies were required to compare at least 2 actively performed CKC exercises for the same scapular muscles to provide a comparison. Studies which assessed individual phases (concentric, isometric, and eccentric) were included as long as they reported values for all phases of the performed exercises.

Studies were excluded if any of the eligibility criteria were not fulfilled. In addition, studies were excluded if all participants had a history of shoulder pathology/injury/pain or current/history of scapular pathology/symptoms within the past 2 years to reduce the potential effects of these factors on EMG activity. Furthermore, studies with no standardized procedure for normalization and analysis of EMG activity for all assessed muscles were excluded.

Quality Assessment

All included studies were assessed independently by 2 reviewers (D.K. and Y.E.) using an adapted version of a standardized quality assessment form for observational studies.¹⁹ This form was

selected because it allows the assessment of each aspect of validity separately instead of a summarized score. It was adapted for this review using modified versions that were used in recent systematic reviews about EMG activity of shoulder muscles during rehabilitation exercises.^{6,12,13}

Data Extraction

Two reviewers (D.K. and Y.E.) extracted relevant information about participant characteristics, methodology, the method of EMG analysis and normalization, exercises tested and result values (mean amplitude value or muscle ratios) using a specifically designed, and prepiloted form, then data extraction was checked by 1 reviewer (D.K.). When there was a disagreement, it was resolved by a third reviewer (D.Ö.K.).

It is considered that the use of resistance does not affect muscle ratios during the exercise.¹³ However, even CKC exercises without an extra load, could be difficult for the general population because body weight creates an axial load.²⁰ If the same exercises were performed with and without resistance in a study,²¹ exercises without resistance were recorded for representing the general population. In addition, in studies comparing isometric exercises that used multiple intensities of force output,²² the maximal force was recorded for analyzing maximal %MVIC due to the clinically more usable nature of maximum force during isometric exercises.

We calculated the ratios as UT/MT, UT/LT, and UT/SA using the %MVIC of the relevant muscles for studies that did not obtain ratios. If %MVIC or muscle ratio of individual phases were reported separately, the values were averaged to obtain a mean value for representing the entire exercise. Data were estimated from graphs in studies that reported their results graphically.

Data Synthesis

Because of discrepancies in EMG analysis methods, normalization procedures, exercises tested, and exercise procedures among studies, a meta-analysis was not conducted.²³ A qualitative synthesis of the findings was performed to identify the muscle ratios elicited from each exercise. We reported pooled means of the ratios for exercises assessed in more than one study and an individual mean for those assessed in a single study. Exercises with muscle ratios <1 indicate that the EMG activities of the MT, LT, and SA are higher than that of the UT. According to the criteria determined by Cools et al,⁷ ratios <0.60 were considered as excellent for the aim of this review. Finally, exercises with muscle ratios >1 indicate that the UT was more active than the other scapular stabilizers.

Evidence Synthesis

Study Selection

The systematic search identified 1284 studies, of which 84 were assessed in full text, and 29 were included for review after screening for eligibility (Figure 1).

Study Characteristics and Methodological Quality

All included studies were cross-sectional designs. One of them²² was a reliability study with test–retest values, and only the test values (rather than retest values) were included in the analysis. Male participants were predominant (66%). Fourteen studies^{15,21,22,24–34} included only males and one study¹⁴ included only females. Furthermore, 3 studies^{32,35,36} specifically included athletes as participants, and one study²¹

Figure 1 — Flowchart of study selection process. EMG indicates electromyography.

included participants who were considered as advanced in resistance training.

All included participants completed the study protocols with no dropout. Eight of the included studies^{15,22,24,26,27,31,35,37} performed a physical examination by a medical professional before testing, and only 2 studies^{25,28} controlled for the presence of scapular dyskinesis. The absence of these examinations may reduce internal validity. However, it is not known how much dyskinesis is pathological³⁸ and the results of this study may still be very relevant to many subjects who have noted dyskinesis but no shoulder pain. All subjects were pain free in our included studies. Blinding of the assessors during testing was not undertaken in any of the studies because of the observational nature of the EMG analysis.

All but 12^{16,17,20,25,28,29,33,35,36,39–41} of the included studies performed exercises using standardized speed and phase durations. All included studies performed appropriate normalization of raw EMG data. Randomization of the exercises was performed in all studies except one³⁰; however, randomization of MVICs was not frequent, and this may affect the internal validity of the results. Summaries of the characteristics and methodological quality for each study were presented in Tables 1 and 2, respectively.

Muscle Ratios

This review identified a total of 81 CKC exercises classified according to their biomechanics (Appendix 2). Among the included studies, EMG activity of the UT was recorded together with the MT during 33 exercises, with the LT during 57 exercises, and with the SA during 79 exercises. Pooled means of the UT/MT, UT/LT, and UT/SA are presented in Figures 2 to 4, respectively. Overall, UT/MT was <1 for 11 exercises, UT/LT was <1 for 24 exercises, and UT/SA

was <1 for 71 exercises, indicating less activation of the UT compared with the other scapular stabilizers. Consequently, 4 exercises for the MT, 9 for the LT, and 59 for the SA were identified as excellent exercises, with ratios <0.60, to activate the specified muscles more than the UT.

Discussion

This review highlights the activity ratios of the scapular stabilizer muscles during common CKC exercises to help guide health professionals in exercise selection when prescribing rehabilitation programs. Restoration of the muscular imbalance via exercises that inhibit UT activity and facilitating the MT, LT, and SA rather than strengthening all scapular muscles is highly recommended by researchers.^{7,37} To determine the optimal exercises for selective strengthening of the scapular muscles, a ratio of at least 0.60 is warranted.⁷ In this review, the pooled means of 4, 9, and 59 exercises for the UT/MT, UT/LT, and UT/SA, respectively, demonstrated that ratios were below 0.60. The results of this review suggest that most of the CKC exercises are optimal exercises for selective activation of the SA, whereas some of them are optimal for selective activation of the MT and LT. All exercises that fall below the 0.60 ratio may be beneficial in restoring scapular muscle imbalance.

Isometric low row (Figure 5A) and inferior glide (Figure 5B) exercises are recommended in early to mid stages of shoulder rehabilitation, because they reveal a low to moderate level of EMG activity in shoulder and scapular muscles.^{46,47} In this review, these exercises had excellent UT/MT, UT/LT, and UT/SA ratios, making them optimal selections to restore muscular balance of the

Table 1 Characteristics of Included Studies^a

Study	Participants	Exercises tested	Muscles assessed	Value used
Andrade et al ²⁴	n = 20 M Mean (SD): age, 22 (3) y Dominant side	One-hand bench press, isometric, on an exercise ball One-hand knee push-up, isometric, on an exercise ball, knees elevated One-hand wall-press, isometric, on an exercise ball	UT and SA	Coactivation index (UT/UT+SA)
Borms et al ⁴²	n = 30 (15 M and 15 F) Mean (SD): age, 23.23 (1.88) y Dominant side	Half supine pull-up with slings, pronated grip Half supine pull-up with slings, supinated grip	UT, MT, LT, and SA	%MVIC
Calatayud et al ²¹	n = 29 M, fit, university students who are considered as advanced in resistance training Mean (SD): age, 22.6 (2.6) y Dominant side	Push-up Push-up on a V-shaped suspension system Push-up on a V-shaped suspension system with a pulley	UT and SA	%MVIC and SA/UT
Castellein et al ⁴³	n = 26 (11 M and 15 F) Mean (SD): age, 33.3 (12.3) y; range 21–56 y Dominant side	Shrug overhead Retraction overhead	UT, MT, and LT	%MVIC
de Araújo et al ²⁶	n = 20 M Mean (SD): age, 22 (3) y Dominant side	One-hand knee push-up, isometric, knees elevated One-hand knee push-up, isometric, on an exercise ball, knees elevated	UT and SA	%MVIC
de Araújo et al ²⁵	n = 18 M from control group Mean (SD): age, 21.50 (2.60) y Dominant side	Push-up, feet elevated Push-up on a wobble board, feet elevated	UT and SA	%MVIC
de Araújo et al ²²	n = 20 M Mean (SD): age, 22 (3) y Dominant side	One-hand bench press, isometric One-hand bench press, isometric, on an exercise ball One-hand knee push-up, isometric, knees elevated One-hand knee push-up, isometric, on an exercise ball, knees elevated One-hand wall press, isometric One-hand wall-press, isometric, on an exercise ball	UT and SA	%MVIC
De Mey et al ⁴⁴	n = 47 (26 M and 21 F) Mean (SD): age, 22 (4.31) y; range 18–30 y Dominant side	Elbow plus, feet lifted Elbow plus with slings, feet lifted Half push-up Half push-up with slings Knee push-up, feet lifted Knee push-up with slings, feet lifted Pull-up, supine, pronated grip Pull-up with slings, supine	UT, MT, LT, and SA	UT/MT, UT/LT, UT/SA, and %MVIC
de Oliveira et al ²⁷	n = 20 M Mean (SD): age, 23 (7) y Dominant side	One-hand bench press, isometric One-hand bench press, isometric, on an exercise ball One-hand push-up, isometric One-hand push-up, isometric, on an exercise ball One-hand wall press, isometric One-hand wall press, isometric, on an exercise ball	UT and SA	%MVIC
Horsak et al ¹⁴	n = 19 F Mean (SD): age, 23 (3) y Right side	Knee plus, hands elevated on a bar Knee plus, on a foam mat Knee plus with slings Knee push-up with plus, hands elevated on a bar Knee push-up with plus, on a foam mat Knee push-up with plus, with slings	UT, LT, and SA	%MVIC

(continued)

Table 1 (continued)

Study	Participants	Exercises tested	Muscles assessed	Value used
Hwang et al ²⁸	n = 29 M Mean (SD): age, 24.72 (2.46) y; range 21–32 y Right side	Plus at 60° shoulder elevation Plus at 90° shoulder elevation Plus at 120° shoulder elevation	UT and SA	UT/SA and %MVIC
Kim et al ³⁹	n = 14 (8 M and 6 F) Mean (SD): age, 23.7 (2.32) y Right dominant side	Knee plus with ipsilateral leg extension Knee plus with ipsilateral leg extension, on a wobble board	UT a SA	%MVIC
Lear and Gross ²⁰	n = 16 (9 M and 7 F) Mean (SD): age for M, 26.9 (3.59) y; range 23–33 y Mean (SD): age for F, 23.9 (3.24) y; range 19–28 y Right side	Push-up with plus, feet elevated Push-up with plus Push-up with plus on a mini trampoline, feet elevated	UT, SA, and LT	%MVIC
Lee et al ²⁹	n = 20 M (n = 10 for exercises performed with slings and n = 10 for exercises performed on a bar) Mean (SD): age for sling exercise group, 23.7 (1.21) y Mean (SD): age for bar exercise group, 23.3 (1.45) y Right dominant side	Knee plus hands elevated on a bar Knee plus hands elevated on a bar, externally rotated shoulders Knee plus hands elevated on a bar, internally rotated shoulders Knee plus with slings Knee plus with slings, externally rotated shoulders Knee plus with slings, internally rotated shoulders	UT, LT, and SA	%MVIC
Lehman et al ³⁰	n = 10 M Mean (SD): age, 26.3 (1.1) y Right-hand side	Plus, hands elevated Plus, hands supported on a ball Push-up, feet supported on a ball Push-up, feet elevated Push-up, hands elevated Push-up, hands supported on a ball	UT, LT, and SA	%MVIC
Ludewig et al ³⁷	n = 19 (7 M and 12 F) from control group Mean (SD): age, 25.2 (3.7) y Dominant side	Elbow plus Knee push-up with plus Push-up with plus Wall push-up with plus	UT and SA	UT/SA and %MVIC
Maenhout et al ¹⁶	n = 32 (14 M and 18 F) Mean (SD): age, 23.33 (1.69) y Dominant side	Plyometric push-up on the Bosu ball Plyometric wall push-up Plyometric wall push-up on the contralateral leg Plyometric wall push-up on the ipsilateral leg	UT, MT, LT, and SA	%MVIC
Maenhout et al ¹⁷	n = 32 (16 M and 16 F) Mean (SD): age, 22.88 (2.43) y Dominant side	Knee plus Knee plus on a wobble board Knee plus with contralateral leg extension Knee plus with contralateral leg extension, one-hand wobble board Knee plus with ipsilateral leg extension Knee plus with ipsilateral leg extension, one-hand wobble board One-hand knee plus	UT, MT, LT, and SA	UT/MT, UT/LT, UT/SA, and %MVIC
Martins et al ³¹	n = 20 M Mean (SD): age, 22.8 (3.1) y Right dominant side	One-hand bench press, isometric One-hand bench press, isometric, on an exercise ball One-hand knee push-up, isometric, knees elevated One-hand knee push-up, isometric, on an exercise ball, knees elevated One-hand wall press, isometric One-hand wall press, isometric, on an exercise ball	UT and SA	UT/SA and %MVIC

(continued)

Table 1 (continued)

Study	Participants	Exercises tested	Muscles assessed	Value used
Park and Yoo ³²	n = 14 M, amateur badminton players Mean (SD): age, 22 (2) y Dominant side	Push-up Push-up on a wobble board	UT, LT, and SA	%MVIC
Pontillo et al ⁴⁵	n = 15 (10 M and 5 F) Mean (SD): age, 30 (6) y Both sides	One-hand knee push-up, isometric One-hand knee push-up, isometric, on a blue TheraBand Stability Trainer One-hand knee push-up, isometric, on a green TheraBand Stability Trainer	UT, LT, and SA	%MVIC
Tucci et al ¹⁵	n = 20 M Mean (SD): age, 22.8 (3.1) y Dominant side	One-hand bench press, isometric One-hand wall press, isometric	UT and SA	%MVIC
Tucker et al ³⁵	n = 15 overhead athletes (4 M and 11 F) Mean (SD): age, 20.4 (3.8) y Dominant side	Cuff Link exercise, elbows full weight-bearing Push-up Push-up on a Bosu ball	UT, MT, LT, and SA	%MVIC
Tucker et al ⁴⁰	n = 20 (10 M and 10 F) Mean (SD): age for M, 26.1 (5.13) y Mean (SD): age for F, 23.9 (5.55) y Dominant side	Cuff Link exercise, full weight-bearing Cuff Link exercise, nonweight-bearing Cuff Link exercise, partial weight-bearing	UT and SA	%MVIC
Tucker et al ³⁶	n = 30 college, overhead (5 M and 10 F) and nonoverhead (5 M and 10 F) athletes Mean (SD): age for overhead M, 21.2 (1.3) y Mean (SD): age for overhead F, 19.5 (1.4) y Mean (SD): age for nonoverhead M, 20.2 (1.3) y Mean (SD): age for nonoverhead F, 19.5 (1.2) y Dominant side	Cuff Link exercise, elbows full weight-bearing Pull-up, supine, pronated grip Push-up	UT, MT, LT, and SA	%MVIC
Vega Toro et al ⁴⁶	n = 65 (27 M and 38 F) Mean (SD): age, 23.52 (3.61) y Both sides	Inferior glide Isometric low row Knee plus Wall press Wall slide	UT, MT, LT, and SA	%MVIC
Yoo and Hwang ³³	n = 12 M Mean (SD): age, 23.1 (1.9) y Right dominant side	Push-up on a wobble board Push-up on wobble board, isometric Push-up on dual wobble boards Push-up on dual wobble boards, isometric Push-up on 1-sided wobble board Push-up on 1-sided wobble board, isometric	UT and SA	%MVIC and SA/UT
Yoon et al ³⁴	n = 14 M Mean (SD): age, 23.0 (1.9) y Right dominant side	Push-up with plus, feet elevated Push-up with plus, feet elevated, externally rotated shoulders Push-up with plus, feet elevated, internally rotated shoulders	UT and SA	%MVIC and SA/UT
Youdas et al ⁴¹	n = 26 (13 M and 13 F) Mean (SD): age for M, 24.5 (4.4) y Mean (SD): age for F, 23.4 (0.87) y Age range, 22–39 y Right side	Pull-up, supine, pronated grip Pull-up, supine, supinated grip Pull-up, supine, pronated grip on single leg support Pull-up, supine, supinated grip on single leg support	UT, MT, and LT	%MVIC

Abbreviations: F, females; LT, lower trapezius; M, males; MT, middle trapezius; %MVIC, percentage of maximum voluntary isometric contraction; SA, serratus anterior; UT, upper trapezius.

a“Plus” exercise defines shoulder protraction by rolling the shoulders forward and then returning to the starting position with shoulder retraction. “Push-up” exercise defines lowering the body by flexing the elbows and then returning to the starting position with extending the elbows. “Push-up with plus” exercise defines a push-up exercise that is performed with the additional shoulder protraction (plus) movement at the end of the pushing.

Table 2 Quality Assessment of Included Studies^a

Study	Internal validity											
	External validity			Performance		Detection		Selection bias/control of confounding				
	Representative	Participation rate	Direct observation	Blinded assessors	Physical examination for participation	Randomization of exercises	Familiarization of exercises	Standardization of exercise technique	Randomization of MVICs	Appropriate normalization procedure	Appropriate statistical tests	Trial to trial reliability
Andrade et al ²⁴	N	Y	Y	N	Y	Y	Y	Y	N	Y	Y	N
Borms et al ⁴²	Y	Y	Y	N	N	Y	Y	Y	N	Y	N	Y
Calatayud et al ²¹	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	N
Castellein et al ⁴³	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N
de Araujo et al ²⁶	N	Y	Y	N	Y	Y	Y	Y	N	Y	N	Y
de Araújo et al ²⁵	N	Y	Y	N	Y	Y	Y	Y	N	Y	Y	N
de Araújo et al ²²	N	Y	Y	N	N	Y	N	N	Y	Y	Y	N
De Mey et al ⁴⁴	Y	Y	Y	N	N	Y	Y	Y	N	Y	Y	N
De Oliveira et al ²⁷	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N
Horsak et al ¹⁴	N	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
Hwang et al ²⁸	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N
Kim et al ³⁹	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	N
Lear and Gross ²⁰	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	Y
Lee et al ²⁹	N	Y	Y	N	N	Y	Y	N	N	Y	Y	N
Lehman et al ³⁰	N	Y	Y	N	N	N	N	N	N	Y	Y	N
Ludewig et al ³⁷	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y
Maenhout et al ¹⁶	Y	Y	Y	N	N	Y	N	N	N	Y	Y	N
Maenhout et al ¹⁷	Y	Y	Y	N	N	Y	N	N	Y	Y	Y	N
Martins et al ³¹	N	Y	Y	N	Y	Y	Y	Y	N	Y	Y	Y
Park and Yoo ³²	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	N
Pontillo et al ⁴⁵	Y	Y	Y	N	N	Y	N	Y	N	Y	Y	N
Tucci et al ¹⁵	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Tucker et al ³⁵	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	N
Tucker et al ⁴⁰	Y	Y	Y	N	Y	Y	Y	N	N	Y	Y	N
Tucker et al ³⁶	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	N
Vega Toro et al ⁴⁶	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y
Yoo and Hwang ³³	N	Y	Y	N	N	Y	Y	N	N	Y	N	N
Yoon et al ³⁴	N	Y	Y	N	N	Y	Y	Y	N	Y	Y	N
Youdas et al ⁴¹	Y	Y	Y	N	N	Y	Y	N	N	Y	Y	N

Abbreviations: MVIC, maximum voluntary isometric contraction; N, no; Y, yes. Note: Physical examination indicates whether the participants were examined by a profession prior to study. Standardization of exercise technique indicates whether studies controlled for the speed and component of exercises during testing.

^aStudy was representative if study sample includes both female and male participants.

Figure 2 — Pooled means (range) of upper/middle trapezius ratios.

shoulder girdle. These exercises focused on a combination of scapular adduction and depression, which is the opposite of the UT function,⁴⁸ and could be the first choice for reducing excessive activation of the UT. Although they were assessed only in one study,⁴⁶ Kibler et al⁴⁷ reported low UT activity with relatively high LT and SA activity (more than 1.5 times) during these exercises in both symptomatic and asymptomatic shoulders.

The use of the shrug exercise performed as an open kinetic chain was not recommended by Schory et al¹³ because of excessive activity of the UT relative to other scapular stabilizers. Similarly, in this review, shrug overhead (the CKC form)⁴³ had the worst ratio in UT/MT and higher UT activity than LT activity. Therefore, we do not recommend prescribing the shrug overhead exercise with the aim of activating the MT and LT. However, none of the studies in our review assessed the activity of the UT and SA together during shrug overhead; therefore, the UT/SA ratio for this exercise is still unknown.

Even though push-up was the most common exercise utilized, none of the variations produced optimal UT/MT ratios. Only the half push-up and knee push-up with lifted feet exercises revealed good muscle ratios (0.60–0.80)⁷ in UT/MT. Although pull-up exercises are not as common as push-ups in the clinical setting, it was found in

this review that all 3 muscle ratios were excellent during half supine pull-ups with slings (Figure 5C).⁴² This exercise may be an option for the restoration of scapular muscle imbalance by selective strengthening of the MT, LT, and SA. However, the results of this exercise were obtained in only one study.⁴² Therefore, this suggestion should be interpreted with caution. In addition, this review found that the UT was less active than the MT and LT during the supine pull-up with a pronated grip exercise.^{36,41,44} However, this exercise had the worst muscle ratios in UT/SA.^{36,44} In this CKC position, the gravitational force will pull the scapula into protraction, and the pronated position of the forearm may force the scapula more upward rotation, anterior tilt, and protraction⁴⁹ and probably feed into a more forward head–shoulder position.⁵⁰ Therefore, the already protracted position of the scapula may be the reason for the high UT/SA ratio by less activation of the SA during supine pull-ups with a pronated grip.

In terms of UT/LT ratio, isometric one-hand knee push-ups (Figure 5D),⁴⁵ irrespective of the surface, had excellent ratios. Moreover, among isotonic push-up variations, excellent ratios for UT/LT were determined in only plus and push-up exercises both with elevated hands.³⁰ The elevated position of the hand (from the floor) may lead to lower humeral elevation angles, and this could

Figure 3 — Pooled means (range) of upper/lower trapezius ratios.

force the scapula to more anterior tilt, and internal and downward rotation.⁵¹ To counter these forces, an increase in the LT activity with a decrease in the UT activity may have occurred and created more optimal ratios of the UT/LT in these exercises. However, it is difficult to draw definitive conclusions because not all CKC exercises which were performed with the elevated position of

the arms had good ratios, and exercises mentioned above were assessed only in individual studies.^{30,45} In addition, it was determined in this review that all variations of knee plus exercises had ratios approximate to or >1 for UT/LT and UT/MT. The relatively low load on the arms in the kneeling position and little movement in the upper extremities during the plus movement may have affected

Figure 4 — Pooled means (range) of upper trapezius/serratus anterior ratios.

the MT and LT activities³⁷ via decreasing stabilization function of these muscles during scapular protraction. We do not recommend using the knee plus exercises for restoring the muscular imbalance between parts of the trapezius.

Our search strategy yielded mostly pushing exercises including the push-up, plus, press, and bench press variations. Therefore, this review revealed that the SA was the most active muscle among these scapular stabilizers with optimal UT/SA ratios during many

Figure 5 — Closed kinetic chain exercises. (A) Isometric low row. (B) Inferior glide. (C) Half supine pull-up. (D) Isometric one-hand knee push-up. (E) Cuff Link exercise, full weight-bearing. (Reprinted from Tucker et al⁴⁰ by permission of Human Kinetics.).

of the exercises reviewed. Although the Cuff Link exercise does not have frequent use clinically, the present review found that the Cuff Link exercises in different weight-bearing conditions^{35,36,40} may be appropriate for the restoration of the muscle imbalance between the SA and UT because they had the lowest UT/SA ratios (<0.20), especially in partial and full weight-bearing conditions (Figure 5E).⁴⁰ In this review, the pooled means of UT/MT and UT/LT for the Cuff Link exercise were calculated only when the position of the elbows was full weight-bearing.^{35,36} UT and MT activation levels were similar and the LT activity was higher than those of the other parts of the trapezius for this exercise. During the other variations of the Cuff Link exercises, the EMG activity of the MT and LT together with the UT should be investigated in further studies to derive more precise conclusions.

Another interesting finding of this review was that all of the pushing exercises with a UT/SA ratio >1 were performed on unstable surfaces. Seven CKC exercises had UT/SA ratios >1 , and 4 of them were pushing exercises performed on unstable surfaces. Besides, most of the pushing exercises performed on unstable surfaces (33 of 37 exercises) had optimal ratios. Therefore, if the aim is higher activation of the SA rather than the UT, caution should be taken when prescribing CKC exercises on unstable surfaces.

Previous researchers have mentioned excessive activation of the UT during open kinetic chain exercises in a standing position because of gravity.⁷ In this review, wall exercises performed in a standing position had UT/SA ratios >0.60 , and UT/MT and UT/LT ratios >1.00 . Wall CKC exercises, such as wall slides and presses, are prescribed in the early stages of the rehabilitation because they

have lower joint loads compared with CKC exercises performed in prone positions.³⁷ Thus, the research suggests that standing wall slides/presses/push-ups may not be appropriate in the early stages of rehabilitation if the primary goal is to achieve a low UT/SA ratio. Still, these exercises may be appropriate in other instances, and the clinician should have a good understanding of the desired goal when prescribing these exercises as part of a comprehensive rehabilitation program.

Limitations

The results of this review are based on a population with healthy, asymptomatic shoulders. Although UT/SA ratios in patients with shoulder dysfunction have been reported to be similar to those of asymptomatic controls during some push-up variations in one study,³⁷ for other types of CKC exercises, whether muscle ratios are different between patients and healthy individuals is still unclear. Nonetheless, these results serve as a good basis for rehabilitation programs for patients with scapular muscle imbalance. However, they should be verified by further studies in symptomatic shoulders.

Many studies have reported only %MVICs. Calculating values from %MVICs rather than original ratios could lead to a deviation from the true value. A few studies have reported eccentric and concentric phase values separately and averaging these may also cause errors. Ekstrom et al⁵² observed that 2 parts of the SA had a similar EMG activity during maximum scapular protraction positions including push-ups. In this review, electrode placement locations varied among studies, and some studies evaluated both upper parts of the SA, whereas some other studies evaluated the

lower parts. However, 2 studies^{25,32} have evaluated the lower and upper parts of the SA separately, rather than using 1 electrode placement area for the SA. Therefore, we analyzed both parts of the SA and pooled these results together for these 2 studies. Differences between studies in the methodology of EMG analysis and normalization, exercise procedures, and inclusion criteria of participants may have affected the results of this review. However, although it is difficult to find studies in which similar procedures of EMG and exercise have been implemented, the inclusion of the studies which have performed EMG normalization and classification of the exercises according to their biomechanics provided us a considerable standardization. Finally, many exercises in this review have been evaluated only in a single study each. Therefore, results must be interpreted with caution for a comparison between these exercises because of the methodological differences between studies.

Conclusions

This review identified the optimal CKC exercises and also those that should be avoided for the restoration of the scapular muscle imbalance in healthy, asymptomatic shoulders. Most CKC exercises tend to activate the SA higher than the UT, and specifically the Cuff Link exercises have the best ratios for the UT/SA. Although there were a few optimal exercise choices for the MT and LT, this review presents CKC exercises that could be used by therapists for the selective strengthening of the MT and LT in the early stages of the rehabilitation process where CKC exercises may be more preferred than the open kinetic chain.⁹ For selective activation of the MT, the isometric low row, inferior glide, and half supine pull-up with slings are the ideal exercises. The isometric one-hand knee push-up variations are the best choice for the LT. Inferior glide, isometric low row, and half supine pull-ups with slings could be the best exercises for high activation of all MT, LT, and SA together with the inhibition of the UT. Some forms of the push-ups or pluses on unstable surfaces may lead to excessive activation of the UT relative to the SA. Moreover, we do not recommend wall CKC exercises for restoring scapular muscle imbalance because of higher activation of the UT compared with the other scapular stabilizers. This review provides a good basis for the guidance of rehabilitation programs conducted clinically and the results of this review should be further investigated in patients with scapular muscle imbalance to determine the effects on ratios and functional outcomes.

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Appendix 1: Search Strategy

PubMed Search Strategy

1. Trapezius (Text Word)
2. Serratus Anterior (Text Word)
3. 1 OR 2
4. Exercise Therapy (MeSH Terms)
5. Exercise (MeSH Terms)
6. Resistance Training (MeSH Terms)
7. Exercise (Text Word)
8. 4 OR 5 OR 6 OR 7
9. Electromyography (MeSH Terms)
10. Electromyography feedback (MeSH Terms)
11. Electromyography (Text Word)
12. EMG (Text Word)
13. Muscle activity (Text Word)
14. 9 OR 10 OR 11 OR 12 OR 13
15. 3 & 8 & 14

Filters: Humans, English or Turkish

EMBASE Search Strategy

1. Trapezius (Text Word)
2. Trapezius muscle (Emtree)
3. Serratus Anterior (Text Word)
4. Serratus anterior muscle (Text Word)
5. 1 OR 2 OR 3 OR 4
6. Exercise (Emtree)
7. Exercise test (Emtree)
8. Exercise (Text Word)
9. Resistance training (Emtree)
10. 6 OR 7 OR 8 OR 9
11. Electromyography (Emtree)
12. Electromyogram (Emtree)
13. Electromyography (Text Word)
14. EMG (Text Word)
15. Muscle contraction (Emtree)
16. 11 OR 12 OR 13 OR 14 OR 15
17. 5 & 10 & 16

Filters: Humans, English or Turkish

CINAHL Plus and SPORTDiscus With Full-Text Search Strategy

1. Trapezius
2. Trapezius muscle
3. Serratus anterior
4. 1 OR 2 OR 3
5. Exercise
6. (Exercise or physical activity)

7. Exercise test
8. Exercise training
9. (exercise training or exercise program)
10. Resistance training
11. 5 OR 6 OR 7 OR 8 OR 9 OR 10
12. Electromyography
13. Electromyogram
14. EMG
15. EMG activity
16. Muscle activity
17. Muscle contraction
18. Electromyography
19. 12 OR 13 OR 14 OR 15 OR 16 OR 17 OR 18
20. 4 & 11 & 19

Filters: English or Turkish

ULAKBIM Turkish Medical Database Search Strategy

1. Trapez
2. Trapezius
3. Serratus anterior
4. 1 OR 2 OR 3
5. Egzersiz
6. Exercise
7. Direnç eğitimi
8. Resistance training
9. 5 OR 6 OR 7 OR 8
10. Electromyography
11. Elektromiyografi
12. EMG
13. Kas aktivitesi
14. Muscle activity
15. 10 OR 11 OR 12 OR 13 OR 14
16. 4 & 9 & 15

Appendix 2: Descriptions of Included Exercises^a

Exercise	Description
Cuff Link exercise, full weight-bearing	Prone with feet supported on the ground and gripping the Cuff Link with elbow extension; rotates counterclockwise while maintaining contact between the Cuff Link and ground
Cuff Link exercise, nonweight-bearing	Standing in front of the Cuff Link that lies on the table, with gripping the Cuff Link with elbow extension; rotates counterclockwise while maintaining contact between the Cuff Link and table
Cuff Link exercise, partial weight-bearing	Kneeling with gripping the Cuff Link with elbow extension; rotates counterclockwise while maintaining contact between the Cuff Link and ground
Cuff Link exercise, elbows full weight-bearing	Prone with placing flexed elbow handles to the holes on the crossarm of the Cuff Link and feet supported on the ground; rotates counterclockwise while maintaining contact between the Cuff Link and ground
Elbow plus	Prone with elbows and feet supported on a stable surface; performs the plus exercise
Elbow plus, feet lifted	Prone with elbows and knees supported on a stable surface, and lifting feet from the ground; performs the plus exercise
Elbow plus with slings, feet lifted	Prone with knees supported on a stable surface, and lifting feet from the ground; elbows hanging on slings which are 10 cm above the ground; performs the plus exercise
Half push-up	In a 45° prone position above a bar with gripping in pronation; performs the push-up exercise
Half push-up with slings	In a 45° prone position above slings with gripping in pronation; performs the push-up exercise
Half supine pull-up with slings, pronated grip	In a half supine position with feet supported on the floor and climbing track, and shoulders in 90° flexion with hands grasping the slings in pronation; pulls upper body up till 90° elbow flexion and lowers back to starting position
Half supine pull-up with slings, supinated grip	In a half supine position with feet supported on the floor and climbing track, and shoulders in 90° flexion with hands grasping the slings in supination; pulls upper body up till 90° elbow flexion and lowers back to starting position
Inferior glide	Seated with 90° of shoulder abduction, full extension of the elbow and neutral position of the wrist; performs shoulder adduction against a small ball while adducting and depressing the scapula
Isometric low row	Standing in front of a fixed table, with the hand palm touching the edge of this table; performs shoulder extension against the edge as isometric while adducting and depressing the scapula
Knee plus	Kneeling on a stable surface; performs the plus exercise
Knee plus, hands elevated on a bar	Kneeling with gripping the push-up bar, and knees supported on a stable surface; performs the plus exercise
Knee plus, hands elevated on a bar, externally rotated shoulders	Kneeling with gripping the push-up bar (10 cm above the ground), shoulders 90° externally rotated and knees supported on a stable surface; performs the plus exercise
Knee plus, hands elevated on a bar, internally rotated shoulders	Kneeling with gripping the push-up bar (10 cm above the ground), shoulders 90° internally rotated and knees supported on a stable surface; performs the plus exercise
Knee plus, on a foam mat	Kneeling with knees supported on a stable surface and placing hands on a foam mat; performs the plus exercise
Knee plus on a wobble board	Kneeling with feet supported on a stable surface and placing hands on wobble board; performs the plus exercise
Knee plus with contralateral leg extension	Kneeling with contralateral leg extension; performs the plus exercise
Knee plus with contralateral leg extension, one-hand wobble board	Kneeling with placing the ipsilateral hand on a wobble board and the contralateral hand on a stable platform that has similar height with the wobble board, and with the extended contralateral leg; performs the plus exercise
Knee plus with ipsilateral leg extension	Kneeling with ipsilateral leg extension; performs the plus exercise
Knee plus with ipsilateral leg extension on a wobble board	Kneeling with ipsilateral leg extension and a wobble board under the opposite knee; performs the plus exercise
Knee plus with ipsilateral leg extension, one-hand wobble board	Kneeling with placing the ipsilateral hand on a wobble board and the contralateral hand on a stable platform which has similar height with the wobble board, and with the extended ipsilateral leg; performs the plus exercise
Knee plus with slings	Kneeling with hands supported on the slings and knees supported on a stable surface; performs the plus exercise
Knee plus with slings, externally rotated shoulders	Kneeling with hands supported on the slings (10 cm above the ground), shoulders 90° externally rotated and knees supported on a stable surface; performs the plus exercise
Knee plus with slings, internally rotated shoulders	Kneeling with hands supported on the slings (10 cm above the ground), shoulders 90° internally rotated and knees supported on a stable surface; performs the plus exercise

(continued)

Exercise	Description
Knee push-up, feet lifted	Kneeling with lifting feet from a stable surface; performs the push-up exercise
Knee push-up with slings, feet lifted	Prone with knees supported on a stable surface, lifting feet from the ground and gripping slings (10 cm above the ground); performs the push-up exercise
Knee push-up with plus	Kneeling on a stable surface; performs the push-up with plus exercise
Knee push-up with plus, hands elevated on a bar	Kneeling with gripping push-up bar and knees supported on a stable surface with 45° angle between femur and ground; performs the push-up with plus exercise
Knee push-up with plus, on a foam mat	Kneeling with hands supported on a foam mat and knees supported on a stable surface; performs the push-up with plus exercise
Knee push-up with plus, with slings	Kneeling with hands supported on a sling suspension and knees supported on a stable surface; performs the push-up with plus movement
One-hand bench press, isometric	Supine, ipsilateral shoulder in 90° flexion with neutral rotation and elbow fully extended to a stable surface; maintains perpendicular compression to the surface.
One-hand bench press, isometric, on an exercise ball	Supine, ipsilateral shoulder in 90° flexion with neutral rotation and elbow fully extended to an exercise ball; maintains perpendicular compression to the ball
One-hand knee plus	Kneeling, knees and ipsilateral hand supported on a stable surface, contralateral hand behind the back; performs the plus exercise
One-hand knee push-up, isometric	Kneeling, knees and ipsilateral hand supported on a stable surface, contralateral hand behind the back; maintains this position
One-hand knee push-up, isometric, knees elevated	Prone with knees flexed and elevated by the wooden box, one shoulder flexed to 90° and in neutral rotation and elbow fully extended on a stable surface; maintains perpendicular compression to the surface
One-hand knee push-up, isometric, on an exercise ball, knees elevated	Prone with knees flexed and elevated by the wooden box, one shoulder flexed to 90° and in neutral rotation and elbow fully extended on an exercise ball; maintains perpendicular compression to the ball
One-hand push-up, isometric	Prone, ipsilateral shoulder in 90° flexion and elbow fully extended and feet supported on a stable surface; maintains this position
One-hand push-up, isometric, on an exercise ball	Prone, ipsilateral arm on an exercise ball (with a fully extended elbow and 90° flexed shoulder) and feet supported on a stable surface; maintains this position
One-hand knee push-up, isometric, on a blue TheraBand Stability Trainer	Kneeling with feet supported on a stable surface and ipsilateral hand on a blue TheraBand® Stability Trainer™ (contralateral hand behind the back); maintains this position
One-hand knee push-up, isometric, on a green TheraBand Stability Trainer	Kneeling with feet supported on a stable surface and ipsilateral hand on a green TheraBand® Stability Trainer™ (contralateral hand behind the back); maintains this position
One-hand wall press, isometric	Standing, ipsilateral shoulder in 90° flexion in neutral rotation and elbow fully extended to the wall; maintains perpendicular compression to the surface
One-hand wall press, isometric, on an exercise ball	Standing, ipsilateral shoulder in 90° flexion with neutral rotation and elbow fully extended to an exercise ball on the wall; maintains perpendicular compression to the ball
Plus at 60° shoulder elevation	Prone with feet and hands supported on a stable surface and shoulders at 60° elevation; performs the plus exercise
Plus at 90° shoulder elevation	Prone with feet and hands supported on a stable surface and shoulders at 90° elevation; performs the plus exercise
Plus at 120° shoulder elevation	Prone with feet and hands supported on a stable surface and shoulders at 120° elevation; performs the plus exercise
Plus hands elevated	Prone with hands supported on the 65-cm high platform and feet supported on a stable surface; performs the plus exercise
Plus hands supported on a ball	Prone with hands supported on the ground and hands supported on the 65-cm exercise ball; performs the plus exercise
Plyometric push-up on a Bosu ball	Kneeling with placing hands on Bosu ball and lifting feet from the ground. No hips flexion. Jump on the Bosu ball with shoulder horizontal abduction/adduction and elbows flexion/extension while maintaining good scapular position and trunk's 1 line position
Plyometric wall push-up	Standing with facing the wall and hands supported at 90° shoulder flexion on the wall; pushes off from the wall until hands are free and then placing hands on the wall again
Plyometric wall push-up on the contralateral leg	Performs the plyometric wall push-up on the contralateral leg with lifting the other leg from the ground
Plyometric wall push-up on ipsilateral leg	Performs the plyometric wall push-up on the ipsilateral leg with lifting the other leg from the ground
Push-up	Prone with elbows in full extension and feet and hands supported on a stable surface; performs the push-up exercise
Push-up, feet supported on a ball	Prone with hands supported on a stable surface and feet supported on the 65-cm exercise ball; performs the push-up exercise
Push-up, feet elevated	Prone with hands supported on a stable surface and feet supported on a high platform; performs the push-up exercise
Push-up, hands elevated	Prone with feet supported on a stable surface and hands on the 65-cm high platform; performs the push-up exercise

(continued)

Exercise	Description
Push-up, hands supported on a ball	Prone with feet supported on a stable surface and hands supported on the 65-cm exercise ball; performs the push-up exercise
Push-up on a Bosu ball	Prone with feet supported on a stable surface, elbows in full extension and hands on the Bosu ball, with the convex side in contact with the surface; performs the push-up exercise
Push-up on a V-shaped suspension system	Prone with gripping bands (10 cm above the ground) of suspension device (TRX Suspension Trainer; TRX, San Francisco, CA) in pronation and feet supported at 10-cm high platform; performs the push-up exercise
Push-up on a V-shaped suspension system with a pulley	Prone with gripping bands (10 cm above the ground) of suspension device (AirFit Trainer Pro; PurMotion, Pelham, AL) that allows greater unilateral suspensions than TRX Suspension Trainer, in pronation and feet supported 10 cm at 10-cm high platform; performs the push-up exercise
Push-up on a wobble board	Prone with feet supported on a stable surface and hands placed on a wooden wobble board; performs the push-up exercise
Push-up on a wobble board, feet elevated	Prone with feet elevated on a platform and hands placed on a wobble board; performs the push-up exercise
Push-up on a wobble board, isometric	Prone with feet supported on a stable surface and hands placed on a wooden wobble board; maintains this position
Push-up on dual wobble boards	Prone with feet supported on a stable surface and hands placed on 2 separate wooden wobble boards; performs the push-up exercise
Push-up on dual wobble boards, isometric	Prone with feet supported on a stable surface and hands placed on 2 separate wooden wobble boards; maintains this position
Push-up on one-sided wobble board	Prone with feet supported on a stable surface, placing the ipsilateral hand on a wooden wobble board and contralateral hand on a stable wooden box; performs the push-up exercise
Push-up on one-sided wobble board, isometric	Prone with feet supported on a stable surface, placing the ipsilateral hand on a wooden wobble board and contralateral hand on a stable wooden box; maintains this position
Push-up with plus	Starting position as the push-up position; performs push-up with plus exercise
Push-up with plus, feet elevated	Starting position as the push-up position; except those feet supported on high platform; performs the push-up with plus exercise
Push-up with plus, feet elevated, externally rotated shoulders	Prone with feet supported on 30-cm high platform and shoulders supported on the floor at 90° external rotation; performs the push-up with plus exercise
Push-up with plus, feet elevated, internally rotated shoulders	Prone with feet supported on 30-cm high platform and shoulders supported on the floor at 90° internal rotation; performs the push-up with plus exercise
Push-up with plus on a mini trampoline, feet elevated	Prone with hands placed on a mini trampoline and feet supported on 45.7-cm high platform; performs the push-up plus exercise
Retraction overhead	Standing with the arms in overhead against the wall and facing the wall; performs a scapular retraction motion and turns back to the starting position
Shrug overhead	Standing with the arms in overhead against the wall and facing the wall; performs a shrug motion and turns back to the starting position
Supine pull-up, pronated grip	In a supine position with feet supported on a stable surface and grasping the bar with both hands in pronation; pulls upper body up and lowers back to the starting position
Supine pull-up, supinated grip	In a supine position with feet supported on a stable surface and grasping the bar with both hands in supination; pulls upper body up and lowers back to the starting position
Supine pull-up, pronated grip on single leg support	In a supine position with ipsilateral feet supported on a stable surface, lifting the contralateral leg, and grasping the bar with both hands in pronation; pulls upper body up and lowers back to the starting position
Supine pull-up, supinated grip on single leg support	In a supine position with ipsilateral feet supported on a stable surface, lifting the contralateral leg, and grasping the bar with both hands in supination; pulls upper body up and lowers back to the starting position
Supine pull-up with slings	In a supine position with feet supported on a stable surface and grasping the slings with both hands in pronation; pulls upper body up and lowers back to the starting position
Wall press	Standing, facing the wall with 90° shoulder flexion, scapular retraction and appropriate feet distance of the feet from the wall; while protracting the scapula (plus) presses hands against the wall and then returns the starting position
Wall push-up with plus	Standing while the hands in contact with the wall in 90° shoulder flexion; performs push-up with plus exercise
Wall Slide	Standing, facing the wall with 90° of the elbow and shoulder flexion and appropriate feet distance of the feet from the wall; slides ulnar side of the forearms up to 150° of shoulder flexion and downward against the wall

^a“Plus” exercise defines shoulder protraction by rolling the shoulders forward and then returning to the starting position with shoulder retraction. “Push-up” exercise defines lowering the body by flexing the elbows and then returning to the starting position with extending the elbows. “Push-up with plus” exercise defines a push-up exercise which is performed with the additional shoulder protraction (plus) movement at the end of the pushing.