http://dx.doi.org/10.1123/ijatt.2014-0047

Serratus Anterior Muscle Activation During Different Push-up Exercises: A Critically Appraised Topic

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Clinical Question: In a healthy adult population, which push-up position produces the greatest mean serratus anterior (SA) activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC)? **Clinical Bottom Line:** In a healthy population, there is moderate evidence to support the use of the standard push-up on an unstable surface, elbow push-ups on stable and unstable surfaces, wall push-ups on an unstable surface, the full weight-bearing position using the Cuff Link system, and all three hand positions (shoulder width, wide base, and narrow base) with and without the use of the Perfect Pushup™ handgrips for the purpose of SA strengthening. These exercises produced a mean SA activation of at least 50% of the MVIC in the four cross-sectional studies that were reviewed for this critically appraised topic.

Clinical Scenario

The serratus anterior (SA) plays a vital role in scapulothoracic motion.[1] Abnormal firing, weakness, or fatigue of the scapular musculature, including the SA, can disrupt normal scapular motion and increase the risk of injury.[2] SA dysfunction has been associated with upper extremity injuries;[3] therefore, many clinicians focus on strengthening the SA to improve upper extremity kinematics for the prevention and rehabilitation of these injuries. Closed kinetic chain exercises, such as push-ups and push-up variations, have been shown to increase neuromuscular control and shoulder stability.[4] However, due to the multiple variations of the push-up, it is unknown which push-up positions have the greatest SA activation. SA activation is often measured through surface electromyography (EMG). Surface EMG records the electrical activity of skeletal muscle and it is generally assumed that exercises producing higher levels of activation will produce greater strengthening effects.[5] Understanding which push-up position will result in the greatest level of SA activation will assist clinicians in their instruction for both prevention and rehabilitation techniques.

Focused Clinical Question

In a healthy adult population, which push-up position produces the greatest mean SA activation, expressed as a percentage of maximum voluntary isometric contraction (MVIC)?

Search Strategy

A computerized search was completed in February 2014 (Figure 1). The search terms used were:

- **P**atient/client group: healthy subjects
- **I**ntervention: serratus anterior AND exercise
- **C**omparison: not applicable
- **O**utcome: muscle activation OR EMG OR electromyography

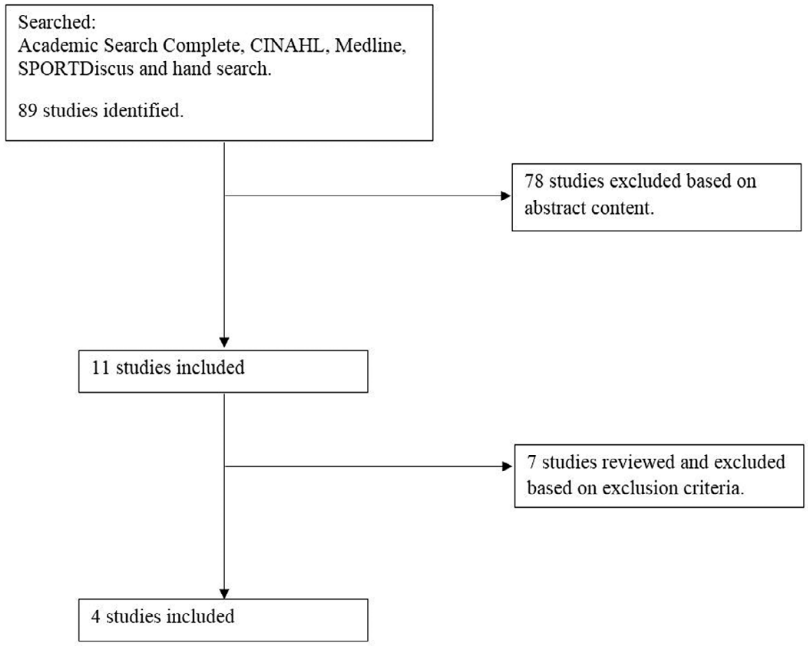

Figure 1 Summary of search history and included studies.

Sources of Evidence Searched

- Medline
- Academic Search Complete
- CINAHL
- SPORTDiscus
- Additional resources were obtained via review of reference lists and hand searches

Inclusion Criteria

- Limited to studies that compared mean SA activation between two or more push-up positions
- Limited to studies that reported mean EMG signal amplitudes of the SA normalized to MVIC
- Limited to studies that are level 3 evidence or higher according to the Oxford Centre for Evidence-based Medicine (OCEBM) Levels of Evidence 1[6]
- Limited to the English language
- Limited to the last 10 years (2005–2014)

Exclusion Criteria

- Studies that included subjects with upper extremity pathology
- Studies that included exercises using a modified push-up position that did not include both hands on a stable or unstable surface, such as the three-point kneeling stance
- Studies that used open kinetic chain exercises
- Studies that measured muscle activation following a fatigue task
- Studies that did not report mean EMG signal amplitudes of the SA normalized to MVIC

Evidence Quality Assessment

Validity of the selected studies was determined using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist for cohort studies, outlined in the STROBE explanation and elaboration doucment.[7] The STROBE was selected as there are no other critical appraisal instruments currently available to critically appraise observational study designs, such as the studies included in this critically appraised topic (CAT). Each author independently reviewed the studies and completed the checklist. All authors met and came to a consensus for each item on the checklist. Some items that were not relevant or applicable to the study design were excluded a priori. For example, any subitem that was open ended, such as "if applicable; consider; if relevant" in addition to the item assessing funding, were marked off of the appraisal instrument and did not count for or against the article's overall score. To receive a point for items that had subitems, the study had to have at least 1/2 of the subitems on the instrument.

Results of Search

Summary of Search, Best Evidence Appraised, and Key Findings

- Three authors (TM, BS, JH) searched the literature for studies of level 3 evidence, based on the OCEBM Levels of Evidence 1,[6] or higher that examined which push-up positions produced the greatest mean SA activation expressed as a percentage of MVIC in healthy subjects. Two authors (TM, JH) met to determine study eligibility and inclusion in the CAT.
- Four[8–11] relevant studies were located (Table 1) that met the inclusion criteria and were included in this CAT. All studies used a cross-sectional, repeated measures study design and were given an OCEBM[6] level 3b designation.
- Each study examined a variety of push-up positions in combination with some form of equipment.
- The knee push-up plus (KPP) with homolateral leg extension demonstrated the greatest SA activation (44.20% $\pm$ 18.67%) when compared with all other KPP exercises ($p < .001$).[8]
- No statistical differences in SA activation were found between the stable and unstable surfaces for: standard push-ups, elbow push-ups, knee push-ups, and wall push-ups.[9]
- When using the Cuff Link system (EFI, San Diego, CA), there was a significant difference in SA activation between the three conditions ($p < .001$), with the greatest SA activation during the full weight-bearing position (81.4% $\pm$ 96.63%).[10]
- There was a significant hand placement effect (shoulder width, wide base, narrow base, $p = .002$) with differences between the shoulder width and narrow base and the wide base and narrow base. An interaction was detected between hand placement and push-up conditions (standard, Perfect Pushup™ handgrips [Perfect Fitness®, Durham, NC]) with the standard push-up with shoulder width position, demonstrating greater SA activation than the Perfect Pushup™ with shoulder width position ($p = .004$).[11]

Results of Evidence Quality Assessment

Two studies[10,11] received a STROBE score of 17/21, while the remaining articles[8,9] received an 18/21. Three studies did not present key elements of the study design early in the paper[8,9,11] or discuss how the study size was arrived at.[8–10] Two studies did not report proper setting characteristics including setting, location, and relevant dates, including periods of recruitment.[8,11] In addition, one study[11] failed to report outcome data or provide information regarding main results, and another[10] failed to provide information regarding all statistical methods performed, as they did not describe their post hoc analyses nor clearly indicate the results of these analyses. Lastly, two studies did not discuss the generalizability of the findings.[9,10]

Clinical Bottom Line

In a healthy population, there is moderate evidence to support the use of the standard push-up on an unstable surface,[9] elbow push-ups on stable and unstable surfaces,[9] wall push-ups on an unstable surface,[9] the full weight-bearing position using the Cuff Link system,[10] and all three hand positions (shoulder width, wide base, and narrow base) with and without the use of the Perfect Pushup™ handgrips[11] for the purpose of SA strengthening in a healthy population. These exercises produced a mean SA activation of at least 50% in the four cross-sectional studies that were reviewed for this CAT.

Strength of Recommendation

Based on the OCEBM Levels of Evidence 1,[6] there is grade B evidence that standard push-ups on an unstable surface,[9] elbow push-ups on stable and unstable surfaces,[9] wall push-ups on an unstable surface,[9] the full weight-bearing position using the Cuff Link system,[10] and all three hand positions (shoulder width, wide base, and narrow base) with and without the use of the Perfect Pushup™ handgrips[11] all demonstrated SA strengthening in a healthy population. According to the OCEBM Levels of Evidence 1,[6] a grade of B is reserved for level 2 or 3 studies, or moderate evidence, with consistent findings across all included studies. Grade A is reserved for consistent level 1 studies, grade C is reserved for consistent level 4 studies or extrapolations from level 2 or 3 studies, and grade D is reserved for level 5 evidence or inconsistent or inconclusive studies from any level.[6]

Implications for Practice, Education, and Future Research

The studies in this CAT examined which push-up positions or equipment generated the greatest mean SA activation. Because of the SA origin at the first through

Table 1. Characteristics of Included Studies

Study Authors	Maenhout et al. (2010)[8]	Sandhu et al. (2008)[9]	Tucker et al. (2005)[10]	Youdas et al. (2010)[11]
Study title	Electromyographic Analysis of Knee Push Up Plus Variations: What is the Influence of the Kinetic Chain on Scapular Muscle Activity?	An Electromyographic Analysis of Shoulder Activation During Push-up Variations on Stable and Labile Surfaces	An Electromyographic Analysis of the Cuff Link Rehabilitation Device	Comparison of Muscle-activation Patterns During the Conventional Push-up and Perfect Push-up Exercises
Study participants	32 healthy, physically active subjects (16 men, 16 women, 22.88 ± 2.43 years)	30 healthy, male subjects ages 20–30; height 173.65 cm ± 2.56; weight 69.9 kg ± 0.2	20 healthy subjects; 10 men (age: 26.1 ± 5.13 years, height: 68.0 ± 2.67 inches, weight: 186.0 ± 25.07 pounds), 10 women (age: 23.9 ± 5.55 years, height: 63.3 ± 2.76 inches, weight: 132.2 ± 17.90 pounds)	20 healthy subjects; 11 men (age 24.9 ± 2.6 years, mass = 79.1 ± 13.4 kg, height = 182.4 ± 7.2 kg), 9 women (age = 23.9 ± 1 years, mass = 58.4 ± 7.1 kg, height = 164.4 ± 6.3 cm)
Inclusion/ exclusion criteria	- No previous history of neck and/or shoulder injury or surgery - Did not participate in high-level overhead sports - Did not perform upper limb strength training for more than 5 hr/week	- No previous history of any injury or surgery to upper or lower limb - No female subjects	- No history of significant shoulder injury - College athletes were excluded - Persons being treated for a heart condition, respiratory condition, high blood pressure, or chronic illness were excluded - Pregnant or possibly pregnant women were also excluded	- No previous history of subluxation, dislocation, fracture, joint instability, tendinitis, bursitis, impingement, adhesive capsulitis, neurovascular complications, or any condition that limited physical activity for greater than 2 days over the last 6 months - No current complaints of neuromuscular pain, numbness, or tingling in the UE, neck, or back

Study Authors	Maenhout et al. (2010)[8]	Sandhu et al. (2008)[9]	Tucker et al. (2005)[10]	Youdas et al. (2010)[11]
Outcome measure	% mean SA maximum voluntary maximum contraction (MVIC) Determined MVIC: - of SA: forward flexion to 130°, resistance applied to further elevation - and 3 other muscles Exercises: - 7 KPP exercises performed in a randomized order: • standard KPP • KPP with heterolateral leg extension • KPP with homolateral leg extension • KPP with wobble board • KPP with heterolateral leg extension and a wobble board • KPP with homolateral leg extension and a wobble board • one-handed KPP - The subjects performed 5 repetitions of each exercise with 5 s of rest in between each repetition and 2 min of rest between each exercise	% mean SA maximum voluntary maximum contraction (MVIC) Determined MVIC: - of SA: forward flexion to 130°, resistance provided to further elevation - and 3 other muscles Exercises: - 4 exercises were performed on stable and unstable surfaces (8 total) in a randomized order: • standard push-up • knee push-up • elbow push-up • wall push-up - The subjects performed 3 repetitions per exercise with 3 min rest between exercises	% mean SA maximum voluntary maximum contraction (MVIC) using Cuff Link system Determined MVIC: - of SA: straight arm wall press - and 3 other muscles Exercises: - The height of each subject was measured to determine the testing procedures (20%, 40%, and 75% of height) - 3 exercises on the Cuff Link were performed in a randomized order: • nonweight-bearing • partial weight-bearing • full weight-bearing - Each trial consisted of 5 revolutions with a 30 s rest period between trials and 2 min rest between positions	% mean SA maximum voluntary maximum contraction (MVIC) using Perfect Pushup™ handgrips Determined MVIC: - using technique from Hislop and Montgomery text - and 3 other muscles using techniques from Hislop and Montgomery text Exercises: - 6 exercises were performed in a randomized order: Push-up positions: • shoulder width • wide • narrow Surface: • floor • Perfect Pushup™ hand grip
Outcome measures	Mean EMG activity normalized to MVIC	Mean EMG activity normalized to MVIC	Mean EMG activity normalized to MVIC	Mean EMG activity normalized to MVIC

(continued)

Table 1. *(continued)*

Study Authors	Maenhout et al. (2010)[8]	Sandhu et al. (2008)[9]	Tucker et al. (2005)[10]	Youdas et al. (2010)[11]
Results	- Mean SA activation ranked in descending order: 1. KPP with homolateral leg extension 2. one-handed KPP, standard KPP 3. KPP with homolateral knee extension and wobble board 4. KPP with a wobble board 5. KPP with heterolateral leg extension 6. KPP with heterolateral leg extension and a wobble board - Significant differences in SA activation between 7 exercises ($p < .001$) with the greatest SA activation during KPP with homolateral leg extension ($p < .001$) - Mean SA activity during KPP with heterolateral leg extension and wobble board was significantly lower than all other exercises ($p < .001$) - SA activity during KPP with heterolateral leg extension is significantly lower than a standard KPP ($p = .001$), KPP with homolateral leg extension with wobble board ($p = .004$), and a one-handed KPP ($p < .001$) - SA activity in a KPP with homolateral leg extension with a wobble board is significantly lower than KPP with homolateral leg extension ($p < .001$)	SA activation for either the concentric or eccentric phases was not significantly affected by the addition of a Swiss ball during any of the push-up variations	- There was significant difference in EMG activity across the three conditions ($p < .001$), with the full weight-bearing position demonstrating the greatest SA activation. - During the nonweight-bearing trial the SA MVIC was minimal; in the partial weight-bearing trial the SA activation was moderate; and during the full weight-bearing trial the SA muscle had significant amount of muscle activation, > 50% of MVIC.	- Significant effect for hand position was found ($p = .002$). For the conventional push-up there were significant differences between the shoulder width and narrow base ($p = .003$) and the wide base and narrow base ($p = .04$). For the Perfect Pushup™ there was a significant difference between the shoulder width and the wide base ($p = .012$). - An interaction was detected, with the conventional push-up demonstrating greater EMG activity than the Perfect Pushup™ in the shoulder width position ($p = .004$).
Level of evidence	3b	3b	3b	3b
Evidence quality score	18/21	18/21	17/21	17/21
Support for the answer	Yes	Yes	Yes	Yes

Note. UE = upper extremity; SA = serratus anterior; KPP = knee push-up plus; EMG = electromyography.

ninth ribs and its insertion on the length of the anterior medial boarder of the scapula, the SA is essential during scapulothoracic motions[1] such as upward rotation of the scapula and scapular protraction. Because of the SA's location and actions, SA dysfunction has been associated with numerous upper extremity injuries.[3] Therefore, clinicians continue to focus on strengthening the SA during rehabilitation or prevention programs. However, at this time it is unclear which exercises, specifically related to push-ups and push-up variations, can produce the greatest mean SA activation indicating that strengthening of the SA is occurring. Due to the numerous positions and equipment used throughout the studies included in this CAT, it is difficult to make an overall conclusion as to which piece of equipment, hand position, or push-up position generates the greatest SA activation. Previous research[12] has stated that muscle activation between 40–60 % of the MVIC would result in strength gains. A study included in this CAT, Tucker et al.,[10] reported that > 50 % of the MVIC is a significant amount of muscle activation. Therefore, when using this threshold value, we can summarize the results of the four studies and which positions or equipment demonstrated the greatest SA activation for incorporation into clinical practice.

Maenhout et al.[8] found the greatest mean SA activation occurred during a KPP with homolateral leg extension (44.20 % ± 18.67 %), followed by the one-handed KPP (36.71 % ± 15.55 %). A KPP with heterolateral leg extension and a wobble board demonstrated the lowest mean SA activation (14.27 % ± 8.14 %).[8] While significant differences were found in mean SA activation between the KPP variations ($p < .001$), none of the exercises reached or exceeded 50 % of the MVIC.[8,10] Because all of the KPP exercises were below 50 % of the MVIC, significant strength gains would be less likely produced. Sandhu et al.[9] reported the mean difference between stable and unstable surfaces, for multiple push-up positions, for both the concentric and eccentric phases of the exercises. Since push-up and push-up variation exercises are rarely performed in eccentric- or concentric-only phases, we have chosen to report which surface and which position demonstrated > 50 % MVIC, indicating strengthening of the SA. The standard push-up on an unstable surface (concentric = 61.72 % ± 40.79 %, eccentric = 45.33 % ± 30.17 %), elbow push-up on a stable surface (concentric = 48.46 % ± 26.93 %, eccentric = 58.81 % ± 30.13 %) and unstable surface (concentric = 62.96 % ± 23.78 %, eccentric = 81.17 % ± 53.94 %), and wall push-ups on an unstable surface (concentric = 60.34 % ± 36.81 %, eccentric = 60.15 % ± 35.7 %) all exceeded the 50 % MVIC level.[9]

Two studies[10,11] used different types of equipment other than the standard wobble board or ball, which included the Cuff Link system and Perfect Pushup™ handgrips. The Cuff Link is a 56-cm diameter circle with a crossbar across the middle.[10] There are insertion holes for placement of the handles, which include the bent-arm, straight-arm, or 45°-angled handles.[10] Tucker et al.[10] used the Cuff Link device with straight-arm handles during three positions of a push-up (nonweight-bearing, partial weight-bearing, and full weight-bearing) and determined the greatest mean SA activation occurred when subjects were in the full weight-bearing position. The only position to exceed the 50 % MVIC was the full weight-bearing position on the Cuff Link (81.4 % ± 96.63 %).[10] The Perfect Pushup™ handgrips elevate the user's hands off the ground and rotate on ball bearings.[11] Youdas et al.[11] used the Perfect Pushup™ handgrips and found all three hand positions (shoulder width, wide base, narrow base) generated > 50 % MVIC for both conventional push-ups and push-ups performed using the Perfect Pushup™ handgrips.[8]

When constructing a rehabilitation or prevention program clinicians may consider using exercises that require a smaller activation in the beginning stages of rehabilitation. Tucker et al.[10] defined mean EMG activity of 0–20 % MVIC as minimal activity, 20–35 % as moderate activity, 35–50 % as moderately strong activity, and > 50 % as significant muscle activation.[10] Therefore, we have summarized the exercises (Table 2) used in all four studies into these categories so clinicians can use the information to create a progression that incorporates exercises targeting the SA and a minimal level, followed by a moderate level, and so on. However, it must be noted that the information presented is for the SA only and all of the studies included used a healthy population. Clinicians must use caution when integrating these exercises if other muscles are affected by the pathology, as some of these exercises recruit other muscles such as the rotator cuff,[9,11] pectoralis major,[9] and triceps.[9,11]

In addition to investigating SA activation, the articles also examined the activation of several other muscles of the shoulder during the push-up variations. None of the KPP variations demonstrated > 50 % MVIC upper, middle, or lower trapezius muscle activation.[8] The pectoralis major demonstrated > 50 % MVIC for

Table 2. Clinical Progression of Exercises for the Serratus Anterior Based on the Muscle Activation (Mean % Maximal Voluntary Isometric Contraction [MVIC]) Categories as Presented by Tucker et al.[10]

Exercise	Mean (Standard Deviation) % MVIC
Minimal activity	
Cuff Link nonweight-bearing	11.33 ± 17.03
KPP with heterolateral leg extension and a wobble board	14.27 ± 8.14
Moderate activity	
KPP with heterolateral leg extension	23.43 ± 14.66
KPP with wobble board	25.30 ± 15.77
Knee push-up on a stable surface	27.43 ± 12.65[a]
KPP with homolateral leg extension and a wobble board	30.46 ± 15.60
Standard KPP	31.65 ± 19.11
Cuff Link partial weight-bearing	34.45 ± 72.69
Knee push-up on labile surface	34.58 ± 16.73[a]
Moderately strong activity	
Standard push-up on a stable surface	45.36 ± 26.95[a]
Wall push-up on a stable surface	48.98 ± 24.63[a]
Significant activity	
Elbow push-up on a stable surface	58.81 ± 30.13[a]
Perfect Pushup™ with a narrow base	65 ± 10[b]
Perfect Pushup™ with shoulder width hand placement	65 ± 10[b]
Wall push-up on a labile surface	60.34 ± 36.81[a]
Standard push-up on a labile surface	61.72 ± 40.79[a]
Conventional push-up with a narrow base	66 ± 12[b]
Elbow push-up on a labile surface	81.17 ± 53.94[a]
Cuff Link full weight-bearing	81.4 ± 96.63
Conventional push-up with wide base	83 ± 10[b]
Conventional push-up with shoulder width hand placement	84 ± 12[b]
Perfect Pushup™ with wide base	84 ± 12[b]

Note. KPP = knee push-up plus.

[a] Denotes only concentric action presented.

[b] Denotes estimation from graph provided in study.

both the eccentric and concentric phases on the stable and unstable surface during a standard push-up, elbow push-up, knee push-up, and wall push-up, except the eccentric phase of a knee push-up on a stable surface.[9] The upper trapezius demonstrated > 50% MVIC for the concentric phase of the standard push-up, knee push-up, and wall push-up for both the stable and labile surfaces.[9] The pectoralis major, deltoid, and trapezius did not demonstrate > 50% MVIC for any of the conditions when using the Cuff Link system.[10] When interpreting the graphs, it appears the pectoralis major demonstrated > 50% MVIC while the deltoid demonstrated minimal to moderate activity for all three hand positions (shoulder width, wide base, narrow base) for both conditions (standard push-up, Perfect Pushup™).[11]

This CAT identifies which commonly-used push-up positions and equipment provide the greatest mean SA activation in a healthy, uninjured population. It is important to note that all of the studies included in this CAT used an uninjured or healthy population.

Therefore, clinicians must use caution that the results of this CAT may not be similar to an injured population. Future research studies should consider utilizing an injured population to determine if these exercises elicit the same responses in SA activation. Due to the lack of high-quality evidence investigating SA activation during various exercises, future research utilizing more rigorous study designs which examine SA activation and potential strength gains over time in healthy populations is warranted. In addition, future research studies should provide measures of central tendency and dispersion for the calculation of effect sizes. The ability to compare effect sizes across studies would enhance the clinical relevance of this CAT. This CAT should be reviewed in two years (2016) to determine whether there is additional best evidence that may change the clinical bottom line for this clinical question. ▮

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