Relationship Between the Closed Kinetic Chain Upper Extremity Stability Test and Strength of Serratus Anterior and Triceps Brachii Muscles

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Key Words

Muscle strength

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Background: The CKCUES test evaluates the functional performance of the shoulder joint. The CKCUES test scores CKC exercises of the upper limbs to examine shoulder stability. Although the CKCUES test provides quantitative data on functional ability and performance, no study has determined the relationship between CKCUES scores and SA and TB muscle strength.

Objects: The objective of this study is to determine the relationship between the CKCUES test scores and the strength of the SA and TB muscles in the CKCUES and unilateral CKCUES tests.

Methods: Sixty-six healthy male volunteers participated in the study. A Smart KEMA strength sensor measured SA and TB muscle strength. Two parallel lines on the floor indicated the initial hand placement to start CKCUES tests. For 15 seconds, the subject raises one hand and reaches over to touch the supporting hand, then returns to the starting position.

Results: The correlation between the CKCUES test scores and the strength of the SA was strong ($r = 0.650$, $p < 0.001$), and the TB was moderate ($r = 0.438$, $p < 0.001$). The correlation between the unilateral CKCUES test and the strength of the SA of the supporting side was strong ($r = 0.605$, $p < 0.001$), and swing side was strong ($r = 0.681$, $p < 0.001$). The correlation between the unilateral CKCUES test and the strength of the TB of the supporting side was moderate ($r = 0.409$, $p < 0.001$), and swing side was moderate ($r = 0.482$, $p < 0.001$).

Conclusion: Our study showed that the CKCUES test had a strong association with isometric strength of SA and moderate association with that of TB. These findings suggest that the CKCUES test can evaluate the function of the SA. Moreover, the unilateral CKCUES test can evaluate unilateral shoulder function.

INTRODUCTION

The shoulder joint is used in daily physical activities, and people can experience various complex joint problems. Shoulder pain and functional disorders are associated with scapular positional impairments and abnormal movements caused by scapular instability [1]. Unstable scapula may lead to inefficiency in the rotator cuff muscles to control the humeral head in the glenoid fossa during overhead elevation. This can contribute to a rupture of the rotator cuff and symptoms of impingement syndrome [2-4].

The serratus anterior (SA) contributes to stability during scapula motions like upward rotation, posterior tilt, and pro-

traction [5], and its normal function is essential in maintaining scapulohumeral rhythm during arm elevation [6]. Inman et al. [7] shows that the SA is the key muscle stabilizing the scapula. Insufficient SA strength is linked to shoulder disorders like winging [8], which increases likelihood of shoulder impingement because scapular upward rotation and protraction are deficient during shoulder abduction [9]. Therefore, muscle strength of scapular stabilizers are essential for rehabilitation and prevention of shoulder disorders and dysfunctions associated with scapular instability.

The clinic, sports, and fitness fields use several tests to determine scapular stability and functionality. These include the lateral scapular slide test [10], scapular load test [11], eccentric

hold test [11], dynamic movement testing, like the one-arm hop test [12], upper quarter Y balance test [13], and closed kinetic chain upper extremity stability test (CKCUES test) [14]. Increased encouragement of functional tests stem from their simplicity, low-cost, and ability to provide vital information on functional performance [15]. Dynamic movement testing, like the one-arm hop test and upper quarter Y balance test, is gaining popularity in muscular screening to help identify increased injury risk [13,16,17]. The CKCUES test is an interesting option for evaluating the stability and functional performance of the shoulder joint [18].

The CKCUES test evaluates the functional performance of the shoulder joint [14]. The CKCUES test scores closed kinetic chain exercises of the upper limbs to examine shoulder stability [14]. It is a simple, low-cost test easily applied in rehabilitation or sports contexts [15]. The subject counts the number of times they touch their other hand for 15 seconds while pushing up. Several studies with a test-retest design found satisfactory reliability levels of CKCUES test scores [14,19]. In addition, the test shows good correlation with grip strength and the peak torque of internal/external shoulder rotation [20].

Although the CKCUES test provides quantitative data on functional ability and performance, no study has determined the relationship between CKCUES scores and SA and triceps brachii (TB) muscle strength. Both provide stability while maintaining a push-up position. In addition, CKCUES starts from the push-up position while touching the hand alternatively. Each side can interdependently affect CKCUES scores. Since the test starts from the push-up position with both hands 36-inches apart, SA and TB strength is essential for supporting body weight. The right side of the scapular and elbow stability can influence the left arm performance for raising and reaching over to touch the right hand. If an individual has weak scapula and/or elbow stabilizers on the right side and normal stability on the left, the CKCUES test score will be low. Alternatively, to raise the hand requires a strong concentric contraction strength of the scapular protractor. The traditional CKCUES test cannot distinguish between right and left-side dysfunctions. Therefore, we assumed that the unilateral CKCUES test (one hand supports and the opposite raises and touches the supporting hand and then returns without alteration) can identify the weaker stabilizing side or the weaker swing side separately. Study of the relationship between the CKCUES test and strength of SA and TB muscles in CKCUES

and unilateral CKCUES tests would be useful to evaluate and treat shoulder dysfunction related to scapular instability.

Therefore, the first objective of this study is to determine the relationship between the CKCUES test scores and the strength of the SA and TB muscles. And, second objective is to determine the relationship between the unilateral CKCUES test scores and the strength of the SA and TB muscles.

MATERIALS AND METHODS

1. Subjects

Sixty-six healthy male volunteers (age: 23.52 ± 3.85 years, body weight: 77.36 ± 5.03 kg, height: 175.42 ± 9.69 cm) participated in the study (Table 1). All participants were injury free, especially in the shoulder, elbow, and wrist joints. The exclusion criteria were (1) history of tears in any muscles and tendons of the shoulder complex, (2) history of subluxation or osteoarthritis in the glenohumeral or acromioclavicular joints, (3) rheumatoid, neurological, or degenerative disease, (4) positive results on Adison and Allen tests, and (5) could not assume the push-up position due to back and extremity pain. The Yonsei University Mirae Campus Human Studies Committee (approval number: 1041849-202002-BM-019-02) approved the study procedure, and all participants provided written informed consent.

2. CKCUES Test and Unilateral CKCUES Test

To start, subjects assumed a push-up position, hands 36-inches apart, and weight-bearing upper extremities positioned perpendicular to the floor and over the hands. Two parallel lines on the floor indicated the initial hand placement. For 15 seconds, the subject raises one hand and reaches over to touch the supporting hand, then returns to the starting position. To determine the relationship between the strength of the swing and supporting sides, we performed unilateral CKCUES tests (Figure 1).

The unilateral CKCUES test has one hand supporting body

Table 1. Characteristics of the subjects

Characteristics	Male (n = 66)
Age (y)	23.52 ± 3.85
Body height (cm)	175.42 ± 9.69
Body weight (kg)	77.36 ± 5.03

Values are presented as mean $\pm$ standard deviation.

Figure 1. Closed kinetic chain upper extremity stability test.

Figure 2. Unilateral closed kinetic chain upper extremity stability test.

weight throughout the test. The other hand raises and touches the supporting hand, then returns to the starting position repeatedly without changing the swing or alternating hands. The test was performed on the right and left sides separately, based on the supporting side. The right unilateral CKCUES test refers to the right-hand supporting side and the swing hand on the left (Figure 2). The principal investigator (PI) demonstrated both the CKCUES and unilateral CKCUES tests for the subjects. After receiving instructions and a demonstration, each subject practiced familiarization with both tests. Then, for data collection, each subject performed two trials for 15 seconds. For the CKCUES test, subjects were asked to touch the supporting hand with the swing hand alternately as quickly as possible for 15 seconds. For the right-side unilateral CKCUES test, subjects were asked to support their body weight with their right hand, raise their left hand, touch the right hand, then return to the starting position repeatedly. For the left-side unilateral CKCUES test, subjects were asked to support their body weight with their left hand, raise their right hand, and touch their left hand. PI counted the number of touches (score). There was a time rest of 45 seconds between trials. A work/rest ratio of 1:3

Figure 3. Measurement of strength of the serratus anterior.

can help avoid fatigue effects during a short and relatively high intensity test, like the CKCUES test [19]. We randomly selected the test orders.

3. Measurement of Strength

The study used a Smart KEMA strength measurement system (Smart KEMA strength sensor; KOREATECH Inc., Seoul, Korea) to measure the isometric strength of SA and TB in kg. We then calculated the average of the two trials. We used load cell to measure static forces of 0–199.9 kg with an accuracy of $0.1 \text{ kg} \pm 2\%$. Smart KEMA software recorded the average strength. In previous studies, Smart KEMA shoulder strength measures showed good to high intra-rater reliability (0.85 to 0.90) [21].

Isometric strength measurements of SA took place in the supine position. Subjects flexed the shoulder joint at 90° and grasped the strap handle connected to the Smart KEMA strength sensor, perpendicular to the ground. The initial tension of the strap was set to 2 kg. The subject performed scapular protraction with maximum force toward the ceiling. The subject's trunk was fixed with an orthopedic belt to minimize trunk rotation. To minimize contraction of the pectoralis major, we asked the subject not to adduct and internally rotate the shoulder joint during protraction of the scapula (Figure 3).

We measured the isometric strength of TB in the supine position. The Smart KEMA tension strap was placed on the distal forearm, 3 cm above the wrist joint. Subjects flexed the shoulder and elbow joint at 90° and supinated the forearm. Before measuring TB strength, the initial tension of the strap was set

to 2 kg. Subjects performed elbow extension maximally against a strap. Subjects held their tested elbow with the opposite hand to stabilize (Figure 4).

4. Statistical Analyses

Statistical analysis was performed using the SPSS for Windows ver. 25.0 software (IBM Co., Armonk, NY, USA). A Shapiro-Wilk test was used to assess whether the scores of the CKCUES and unilateral CKCUES tests and the isometric strength of the SA and TB were normally distributed. The study found that they were, so Pearson's correlation was used to determine the relationship between the test scores and the isometric strength of SA and TB. The strength of association was classified based on those of the British Medical Journal: 0–0.19 very weak, 0.2–0.39 weak, 0.40–0.59 moderated, 0.6–0.79 as strong, and 0.8–1 very strong [22]. In all analyses, statistical significance was set at $p < 0.05$.

RESULTS

Table 2 shows the mean and standard deviation of the CKCUES test scores. Table 3 shows the mean and standard deviation

Figure 4. Measurement of strength of the triceps brachii.

tion of the strength of SA and TB. The correlation between the CKCUES test scores and the strength of the SA (average of both sides) was strong ($r = 0.650$, $p < 0.001$), and the TB was moderate ($r = 0.438$, $p < 0.001$) (Table 4). The correlation between the unilateral CKCUES test and the strength of the SA of the supporting side was strong ($r = 0.605$, $p < 0.001$), and swing side was strong ($r = 0.681$, $p < 0.001$). The correlation between the unilateral CKCUES test and the strength of the TB of the supporting side was moderate ($r = 0.409$, $p < 0.001$), and swing side was moderate ($r = 0.482$, $p < 0.001$) (Table 5).

DISCUSSION

This study investigated the relationship between CKCUES test scores and isometric strengths of SA and TB. The CKCUES test had a strong association with the isometric strength of SA and moderate association with that of TB. The CKCUES test is widely used as a dynamic shoulder stability function test. In this study, the mean score of the CKCUES test was 30.87. These results are consistent with Tucci et al. [14], who demonstrated a mean CKCUES test score of 27.13 for young healthy males.

The push-up position is widely recommended for recruiting scapular muscles [23], especially in shoulder rehabilitation [24]. Specifically, in many studies the position is used to strengthen the SA [25]. Mosely et al. [26] included the standard push-up plus as a core exercise in their shoulder rehabilitation program based on the high electromyographic activity of several shoulder muscles, including the SA. Park et al. [27] investigated electromyography of SA during various push-up plus exercises. They showed that standard push-up plus is an optimal exercise for subjects with scapular winging, with maximum activation

Table 2. CKCUES test

Variable	Score
CKCUES test (number)	16.67 ± 4.52
Rt side unilateral CKCUES test (number)	12.30 ± 3.35
Lt side unilateral CKCUES test (number)	12.53 ± 3.11

Values are presented as mean $\pm$ standard deviation. CKCUES test, closed kinetic chain upper extremity stability test; Rt, right; Lt, left.

Table 3. Strength of SA and TB

	Average of both side (n = 66)	Right side (n = 132)	Left side (n = 132)
SA strength (kg)	30.87 ± 8.61	30.75 ± 8.41	30.98 ± 9.22
TB strength (kg)	16.48 ± 4.86	6.61 ± 5.44	6.61 ± 5.44

Values are presented as mean $\pm$ standard deviation. SA, serratus anterior; TB, triceps brachii.

of the SA and minimal activation of the pectoralis major [27]. This is the first study to investigate the relationship between the CKCUES test and SA strength. The SA is one of the most important muscles for maintaining normal scapular alignment in the shoulder joint. It helps prevent winging or anterior tilting of the scapula [28]. Celik et al. [29] showed that subjects with shoulder impingement syndrome have lower SA strength on the impinged side. Tucci et al. [14] reported that the CKCUES test score was lower in subjects with shoulder impingement syndrome than in those without. These results indicate that the CKCUES test can evaluate the strength of SA and can identify and monitor the risk of shoulder impingement syndrome.

Previous studies have modified the CKCUES test in various ways. Tucci et al. [14] applied the CKCUES test in a kneeling position to evaluate females. Taylor et al. [30] states that having a narrower shoulder width or shorter arm span places athletes at a disadvantage when performing the CKCUES test. For this reason, they modified the CKCUES test to place the hands directly under their shoulders [30]. Degot et al. [31] suggested that a fourth 1 minute set performed after a 15-second recovery following the third set can reflect muscular endurance capacity. However, because all CKCUES test methods evaluate both hands alternately, it was unclear whether the strength of the swing or supporting sides was more significant. In our results, the correlation between the unilateral CKCUES test scores and the strength of the swing side SA and TB was higher than the supporting side ($r = 0.681$ vs. $r = 0.635$). The correlation between the unilateral CKCUES test scores and the strength of the swing side SA was higher than between the CKCUES test scores and the average strength of the SA on both sides ($r =$

0.681 vs. $r = 0.650$). This indicates that the SA strength of the swing side is more strongly correlated with the unilateral CKCUES test score than the strength of the supporting side during the CKCUES test. This may be because the swing side requires concentric contraction strength to raise the hand and lift body weight with scapular protraction than stabilizing the scapula on the supporting side. Although SA strength in the swing and supporting sides were similar, the correlation was slightly different between both sides in the unilateral CKUES test ($r = 0.681$ vs. $r = 0.635$). When the CKCUES test was performed for individuals with similar SA strength in both sides, the unilateral CKCUES test could identify the weaker side.

With the CKCUES test, the isometric strength of TB showed a relatively lower relationship (moderated) than SA. This result is likely because elbow rocking is possible during the CKCUES test. Torres et al. [32] showed no significant difference in muscle activity of TB with or without a stable surface during push-up plus. Lehman et al. [33] showed that due to the mechanical advantage of TB in forearm length, responding to changes in stability during push-ups may be difficult. Therefore, if the strength of TB for the CKCUES test is insufficient, elbow rocking can compensate.

Our study had several limitations. First, our results cannot be generalized because all subjects were male. Further research is necessary to establish the application to women. Second, the core stability and strength of other upper extremity muscles involved in performing the CKCUES test were not measured. Third, since only healthy subjects participated, it is unclear whether the CKCUES test scores are different in subjects with unilateral shoulder disorders. Further research is necessary to determine whether the unilateral CKCUES test scores are different between the normal and impaired sides in subjects with unilateral shoulder disorders.

Table 4. Correlation between the CKCUES test scores and average strength of both sides

Variable	SA average strength of both sides	TB average strength of both sides
CKCUES test	0.650**	0.438**

CKCUES test, closed kinetic chain upper extremity stability test; SA, serratus anterior; TB, triceps brachii. ** $p < 0.05$.

CONCLUSIONS

Our study showed that the CKCUES test had a strong association with isometric strength of SA and moderate association

Table 5. Correlation between the unilateral CKCUES test and strength of SA and TB

Variable	SA strength of supporting side	SA strength of swing side	TB strength of supporting side	TB strength of swing side
Unilateral CKCUES test	0.635**	0.438**	0.409**	0.482**

CKCUES test, closed kinetic chain upper extremity stability test; SA, serratus anterior; TB, triceps brachii. ** $p < 0.05$.

with that of TB. These findings suggest that the CKCUES test can evaluate the function of the SA. Moreover, the unilateral CKCUES test can evaluate unilateral shoulder function.

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CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Conceptualization: YW, OK. Data curation: YW. Formal analysis: YW, SA, JK, GG. Investigation: YW. Methodology: YW, SA, JK, GG, OK. Resources: YW, SA, JK, GG, OK. Supervision: SA, JK, GG, OK. Validation: SA, JK, GG, OK. Visualization: YW. Writing - original draft: YW. Writing - review & editing: SA, JK, GG, OK.

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