Biceps Disorder Rehabilitation for the Athlete

A Continuum of Moderate- to High-Load Exercises

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Background: Progressive biceps loading is recommended in the nonoperative and operative rehabilitation of biceps-related disorders. Previous researchers have proposed a continuum of exercises with low to moderate biceps loads to be used in the early and intermediate phases of rehabilitation. A progression of exercises with moderate to high biceps loads to be used in the more advanced phases of rehabilitation is lacking.

Purpose: To describe a progression of exercises with progressive moderate to high loads on the biceps brachii (BB) based on electromyographic (EMG) analysis.

Study Design: Controlled laboratory study.

Methods: The EMG activity of BB and triceps brachii; upper trapezius, middle trapezius, and lower trapezius; and serratus anterior was determined with surface electromyography in 30 asymptomatic participants during 11 exercises.

Results: Of the 11 exercises, 4 (arm shake with an Xco-trainer, lateral pull-down in pronation, chest shake with an Xco-trainer, lateral pull-down in supination) showed low (<20% maximal voluntary isometric contraction [MVIC]), 5 (pull-up in pronation with Redcord, air punch, forward flexion in supination, pull-up in supination with Redcord, inclined biceps curl) showed moderate (between 20%-50% MVIC), and 2 (throwing forward flexion, reverse punch) showed high (>50% MVIC) EMG activity in the BB. These exercises were ranked with an increasing level of activity in the BB.

Conclusion: The continuum of exercises with moderate to high biceps activity may be applied in the more advanced phases of treatment for biceps disorders. In addition, biceps muscle activity may be targeted by (1) sagittal plane elevation; (2) elbow flexion with supination, without upper arm support; (3) biceps contraction from an elongated position; or (4) high-velocity, explosive exercises.

Clinical Relevance: These findings may assist clinicians to select appropriate exercises to be used in the more advanced phases of nonoperative or postoperative rehabilitation of overhead athletes with biceps-related injuries.

Keywords: electromyography; biceps injury; exercise treatment; biceps brachii

Shoulder injuries are commonplace in overhead-throwing athletes as a result of high loads on the shoulder joint during overhead throwing.[4] Anterior shoulder pain, in particular, is often generated by long-head biceps tendon injuries.[2,33] These injuries include tendinitis,[1,43] partial- or full-thickness tears,[18,37] biceps tendon instability (subluxation or dislocation),[1,37,43] and superior labrum anterior-posterior (SLAP) lesions.[1,18,31,37]

Biceps-related shoulder injuries can occur due to a number of causes, including a traumatic event or chronic overuse such as repetitive overhead throwing.[40] During an overhead throw, biceps injuries can be caused by the peel-back phenomenon in the late cocking phase and by substantial biceps muscle eccentric contraction to decelerate the elbow extension during the follow-through phase.[5,19] Other possible underlying factors in the development of biceps tendon degeneration, such as SLAP lesions, are pathological glenohumeral internal rotation deficit, kinetic chain deficits, scapular dyskinesia, and internal impingement.[40]

Biceps-related conditions are treated operatively or nonoperatively, depending on concomitant injuries, injury cause, and severity of the injury. For overhead athletes, suggestions have been made for the initial treatment to be nonoperative,[4,32,36] with the focus on strengthening all elements of the kinetic chain, including trunk, core, and lower limb training. For upper limb training, muscle imbalances in scapulothoracic and rotator cuff (RC) muscles

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should be restored[4,36,43] in combination with posterior shoulder stretching[17,36] and progressive biceps muscle strengthening.[43] Operative treatment is indicated when nonoperative treatment has failed or when structural deficits need to be repaired.[32,36,43] Postoperative rehabilitation programs are well documented, with specific guidelines in every phase after surgery, depending on the type of surgery performed.[36,37] In the first phase, no or minimal biceps activity is recommended, since protection of the injury site is crucial.[36] In the next phase, biceps load must be progressively restored with the use of strength training and plyometric training. In the final phase, biceps load during rehabilitation should meet sport-specific requirements. For overhead athletes in particular, gradual return to overhead throwing is necessary to achieve full, unrestricted sports participation. Besides common overhead sports like baseball, volleyball, softball, and tennis, the less traditional ones like pole vaulting, javelin, and gymnastics also have to be taken into account. In gymnastics, a great amount of stress is brought upon the shoulder joint, involving bilateral and multidirectional loads and stresses,[7,15] making it the most commonly injured upper body region (range, 4.6%-19.1%).[6] De Carli et al[12] found magnetic resonance imaging abnormalities in all 36 elite male gymnasts in their study, with 44% of gymnasts' shoulders presenting with involvement of the long head of the biceps tendon and 83% with labral irregularities of which 44% were defined as SLAP lesions. Those SLAP lesions were most frequent in athletes performing gymnastics on the rings. During the suspension phase of a backward swing on the rings, high mechanical loads on the shoulder joint are generated while muscle activity values are low.[7] This loaded suspension might explain the vertical pull on the biceps anchor, possibly leading to a displacement of the long head of the biceps tendon from the superior glenoid labrum causing a SLAP lesion.[7,21] During rehabilitation, traditional exercises using barbells and dumbbells could be performed.[3] However, these types of exercises do not reproduce the same loads and movements used on the rings. Moreover, sport-specific training is often desirable during the more advanced phases of rehabilitation to prepare the athlete for return to play.

Several studies have used electromyographic (EMG) analysis to quantify shoulder muscle activity so that appropriate exercises could be selected during every phase of rehabilitation.[11,20,42] Previous research has mainly focused on EMG activity of scapulothoracic, deltoid, or RC muscles.[11,20,42] Hence, exercises are already available to improve scapulohumeral rhythm, restore scapulothoracic or RC muscle imbalances, and increase overall shoulder and scapular stability. These exercises are frequently used for treatment of various shoulder disorders, such as shoulder impingement.[24,26] However, the literature is limited concerning biceps brachii (BB) muscle EMG activity, especially in conjunction with scapular and glenohumeral muscle activity. Nevertheless, progressive activation of the BB while targeting specific scapular or glenohumeral muscles is crucial during the conservative or postoperative rehabilitation of biceps-related shoulder injuries since restoring imbalances in these muscles could also be a part of treatment in biceps-related rehabilitation of overhead athletes. Only 1 study has investigated BB EMG activity in combination with scapulothoracic and glenohumeral muscles during commonly used rehabilitation exercises.[9] All exercises were ranked with an increasing level of EMG activity in the BB. Out of the 16 exercises tested, 13 showed low BB activity (<20% maximal voluntary isometric contraction [MVIC]), while only 3 showed moderate BB activity (20%-50% MVIC). EMG activity of the BB never surpassed 35.9% of MVIC, suggesting that all 16 exercises should instead be used in the early and intermediate phases of rehabilitation of biceps-related pathologic conditions. Nonetheless, these authors failed to select exercises with high BB activity (>50% MVIC), appropriate for the more advanced phases of rehabilitation of BB-related disorders. For overhead-throwing athletes, high biceps load during sport-specific activities should be simulated in the final phases of rehabilitation before the athlete can return to full and unrestricted sports activity. The aim of this study was to examine the EMG activity of the BB in exercises specifically chosen for targeting moderate to high BB activation. By ranking these exercises according to increasing BB activity, our intent was to suggest a continuum of exercises to be used in the intermediate to advanced and final phase of rehabilitation of overhead-throwing athletes with biceps-related disorders. We hypothesized that all exercises will exhibit moderate (20%-50% MVIC) or high (>50% MVIC) EMG activity of the BB and that none will exhibit low BB EMG activity (<20% MVIC).

METHODS

Subjects

The a priori power analysis for this study was set at 80%, based on an alpha level of .05, resulting in a minimal sample size of 30. Thirty healthy volunteers were recruited for participation in this study (15 men, 15 women). Mean (±SD) age, height, weight, and body mass index were, respectively, 23.23 ± 1.88 years, 1.76 ± 0.009 m, 71.25 ± 11.01 kg, and 22.82 ± 2.61 kg/m^2. All subjects were in good general health, had absence of pain or dysfunction in the shoulder or cervical spine during the 6 months before testing, and did not have a history of shoulder or cervical spine surgery. Subjects were excluded if they participated in competitive overhead sports or performed high-level upper extremity strength training for more than 5 hours per week. Written informed consent was acquired from all participants, and approval for this study was obtained by the Ethical Committee of Ghent University.

Instrumentation

A wireless Telemyo Direct Transmission System (DTS; Noraxon Inc) was used for EMG data collection. First, the skin on the dominant shoulder was shaved, scrubbed, and prepared with alcohol to reduce skin impedance ($<10\ \kappa\Omega$). Second, bipolar surface electrodes (Ambu BlueSensor P; Ambu

TABLE 1
Exercise Descriptions

No.	Exercise	Description
1	Lateral pull-down in pronation[16,45]	Subject sits in front of a pulley apparatus, with shoulders in full elevation, elbows fully extended, and hands slightly wider than shoulder width holding the bar in pronation. Subject performs shoulder adduction and elbow flexion in the scapular plane until the bar reaches chin level.
2	Lateral pull-down in supination[44]	Subject sits in front of a pulley apparatus, with shoulders in full elevation, elbows fully extended, and hands slightly wider than shoulder width holding the bar in supination. Subject performs shoulder adduction and elbow flexion in the scapular plane until the bar reaches chin level.
3	Pull-up in pronation with Redcord[14]	Subject is in supine plank position with shoulders in 90° forward flexion and only heels touching the ground with metatarsophalangeal joint supported by the lowest rung of a climbing track. Hands grasp the Redcord handles in pronation. Subject performs a pull-up until 90° elbow flexion while maintaining neutral spine alignment and keeping heel contact with the floor.
4	Pull-up in supination with Redcord	Subject is in supine plank position with shoulders in 90° forward flexion and only heels touching the ground with metatarsophalangeal joint supported by the lowest rung of a climbing track. Hands grasp the Redcord handles in supination. Subject performs a pull-up until 90° elbow flexion while maintaining neutral spine alignment and keeping heel contact with the floor.
5	Inclined biceps curl with dumbbell[39]	Subject sits in 50° trunk extension, and dominant arm hangs vertically along the body with elbow supination. Subject performs a full elbow flexion in supination while maintaining vertical alignment in the upper arm.
6	Forward flexion in external rotation and forearm supination with dumbbell[9]	Subject stands with the dominant arm at the side in external rotation and forearm supination. Subject performs forward flexion in a sagittal plane to 90°.
7	Throwing forward flexion in 90° with soft weight ball	Subject stands with dominant arm in 90° forward flexion and supination in a sagittal plane. Subject performs a forward flexion to throw the ball in the air, followed by a delayed catch of the ball in 90° forward flexion.
8	Arm shake with Xco-trainer[22]	Subject stands with dominant arm in 90° shoulder abduction with external rotation and 90° elbow flexion with pronation. The Xco-trainer is in the lateral position. Subjects performs alternating elbow flexion and extension (moving closer and further away from the ear) without moving the body elsewhere. The sand should be heard when reaching both sides of the Xco-trainer.
9	Chest shake with Xco-trainer[22]	Subject stands with dominant arm in 45° scapular plane elevation and 90° elbow flexion with neutral forearm rotation. Subject performs alternating elbow flexion and extension (moving closer and further from the chin) without moving elsewhere in the body. The sand should be heard when reaching both sides of the Xco-trainer.
10	Air punch[27,28]	Subject stands with dominant upper arm along the body and elbow fully flexed in supination. Subject performs a forward punch in a sagittal plane with shoulder in 90° forward flexion and full elbow extension with pronation.
11	Reverse punch with elastic tubing	Subject stands with dominant upper arm in 90° forward flexion and full elbow extension with pronation. Subject performs a reverse punch in a sagittal plane by fully flexing the elbow in supination against elastic tubing resistance and with the upper arm vertically aligned along the body.

A/S) were placed over the serratus anterior (SA); the upper trapezius (UT), middle trapezius (MT), and lower trapezius (LT); and the BB and triceps brachii (TB). Surface EMG for the noninvasive assessment of muscles (SENIAM) recommendations were followed for electrode placement and interelectrode distance.[25] Third, the DTS probes were connected to each of the electrodes, as they transmit the EMG data to the receiver. The sampling rate was 1500 Hz, and all raw myoelectric signals were preamplified (overall gain, 500; common rate rejection ratio, >100 dB; signal-to-noise ratio, <1μV root mean square baseline noise). Correct electrode placement was checked by visual inspection of the EMG signal during muscle-specific movements. In addition, an OptiTrack high-speed camera (FPS) was used to collect kinematic data during all exercises. Reflective markers were applied to the dominant upper limb of the subject with double adhesive tape (marker placement was exercise dependent). The camera was installed perpendicular to these reflective markers.

Exercise Selection

A total of 11 exercises were selected for this study, based on a systematic literature search on biceps EMG activity during rehabilitation exercises, assuming that these exercises would elicit moderate (20%-50% MVIC) to high (>50% MVIC) BB activity.[9,16,22,28,39,45]: (1) lateral pull-down in pronation, (2) lateral pull-down in supination, (3) pull-up in pronation with Redcord (Redcord AS), (4) pull-up in supination with Redcord, (5) inclined biceps curl (IBC) with dumbbell, (6) forward flexion in external rotation

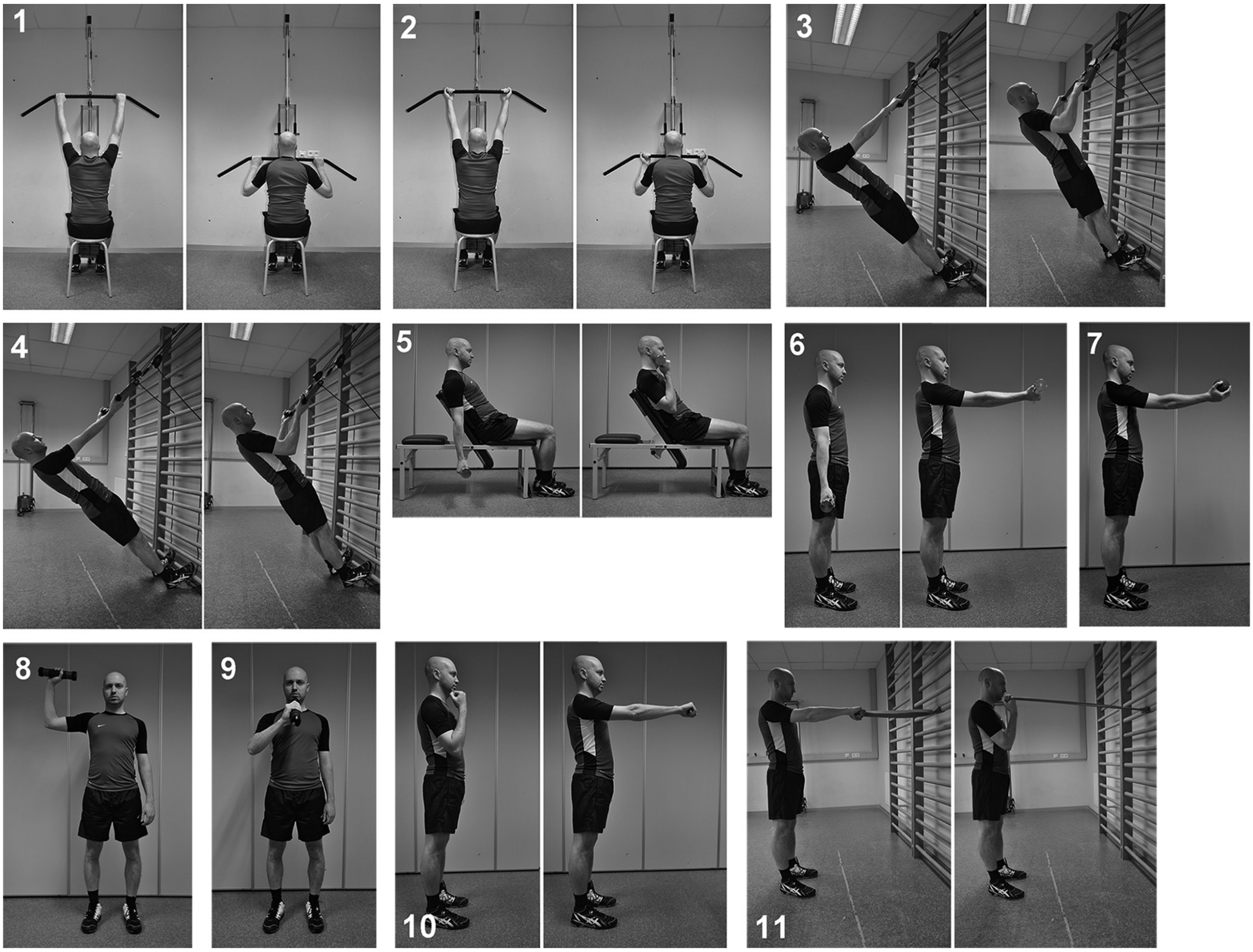

Figure 1. Demonstrating the 11 exercises studied: (1) lateral pull-down in pronation, (2) lateral pull-down in supination, (3) pull-up in pronation with Redcord, (4) pull-up in supination with Redcord, (5) inclined biceps curl with dumbbell, (6) forward flexion in external rotation and forearm supination with dumbbell, (7) throwing forward flexion in 90° with soft weight ball, (8) arm shake with Xco-trainer, (9) chest shake with Xco-trainer, (10) air punch, and (11) reverse punch with elastic tubing.

and forearm supination with dumbbell, (7) throwing forward flexion in 90° with soft weight ball, (8) arm shake with an Xco-trainer (Flexi Sports GmbH), (9) chest shake with an Xco-trainer, (10) air punch, and (11) reverse punch with elastic tubing. All exercises are described in Table 1 and illustrated in Figure 1. Videos of all exercises are provided in the Video Supplement.

Testing Procedure

MVIC was measured for all selected muscles. For the UT, subjects were seated with the arm in 90° of abduction in the frontal plane, and isometric resistance was applied to further abduction.[8] For the MT, MVIC was measured in the prone position with the arm in 90° of abduction and external rotation, with resistance to horizontal abduction. For the LT, subjects were lying prone, and resistance was applied to maximal forward flexion. For the SA, participants were seated, and resistance was applied to 135° of forward flexion. For both BB and TB, subjects were seated in 90° of elbow flexion.[29] Resistance was applied to elbow flexion in supination for BB and to elbow extension in neutral forearm rotation for TB. Under verbal encouragement, subjects were instructed to perform the contraction up to a maximal effort. Three MVICs of 5 seconds with 15 seconds of rest in between were completed. After demonstration and instruction by the researcher, all 11 exercises were performed in randomized order. Quality of exercise execution was checked and corrected when necessary, before recording muscle activity. For exercises using an external resistance (1-2, 5-9, and 11), an individual resistance for each exercise was selected based on sex and body weight[9,10,13] (see the Appendix, available in the online version of this article).

The number of repetitions was exercise dependent and was chosen to have an equal duration of 30 seconds for each exercise. Exercises 1 to 6 were repeated 5 times, and each repetition consisted of a 3-second concentric and 3-second eccentric phase. Exercises 7, 10, and 11 were performed at 1 repetition/s for a total of 30 repetitions. Exercises 8 and 9 consisted of 60 repetitions since these exercises were

TABLE 2
Electromyogram Activity of Each Muscle for the 11 Exercises[a]

	% MVIC[b]					
Exercise No.	UT	MT	LT	SA	BB	TB
1	7.90 ± 9.13	24.30 ± 16.18	37.45 ± 53.50	61.35 ± 40.59	16.86 ± 8.93	17.43 ± 8.87
2	7.10 ± 6.71	24.62 ± 19.54	35.82 ± 51.71	58.72 ± 42.66	18.92 ± 9.35	17.19 ± 9.31
3	30.25 ± 13.75	57.11 ± 31.20	52.28 ± 40.67	61.12 ± 56.54	24.06 ± 17.26	22.73 ± 16.49
4	22.24 ± 15.61	43.94 ± 28.48	50.81 ± 55.73	68.88 ± 75.92	41.96 ± 28.20	23.37 ± 15.28
5	16.88 ± 11.00	17.01 ± 15.23	17.11 ± 12.71	38.31 ± 23.33	43.99 ± 19.85	11.26 ± 6.71
6	46.72 ± 16.55	30.80 ± 22.82	36.53 ± 40.18	94.26 ± 46.73	35.56 ± 24.85	21.69 ± 14.75
7	57.52 ± 18.03	29.89 ± 17.17	37.06 ± 40.09	122.48 ± 46.53	56.96 ± 41.63	33.40 ± 16.31
8	28.96 ± 10.53	39.52 ± 27.34	38.86 ± 24.71	42.59 ± 23.14	14.97 ± 10.83	21.13 ± 9.21
9	15.48 ± 6.50	15.84 ± 10.78	26.41 ± 28.83	40.13 ± 23.11	17.26 ± 9.01	16.43 ± 6.63
10	25.39 ± 9.76	23.96 ± 26.46	28.50 ± 32.44	68.92 ± 60.25	27.58 ± 19.55	20.65 ± 10.35
11	30.45 ± 10.99	46.83 ± 41.01	54.41 ± 54.02	65.77 ± 33.88	67.37 ± 25.46	22.28 ± 10.48

[a] Data are reported as mean ± SD. BB, biceps brachii; LT, lower trapezius; MT, middle trapezius; SA, serratus anterior; TB, triceps brachii; UT, upper trapezius.

[b] Shading indicates grading for percentage maximal voluntary isometric contraction (MVIC): no shading = low (<20% MVIC); light gray–shaded cells = moderate (20%-50% MVIC); dark gray–shaded cells = high (>50% MVIC).

executed at 2 repetitions/s. A metronome was used to ensure correct speed during exercise performance. Between 2 different exercises, 4 minutes of rest were provided.

Signal Processing and Data Analysis

The myoVIDEO module of the Noraxon MR 3.4 software program was used for signal processing. After cardiac artefact reduction, rectification, and smoothing (RMS, 50 ms), the EMG signals in the 3 intermediate seconds of the MVIC measurement were calculated and averaged. The analysis of marker motion identified the start and end of each repetition for all exercises. Mean EMG activity for every muscle was calculated across the 18 intermediate seconds for all exercises. The first and last 6 seconds were dismissed because of habituation and fatigue purposes.[13] Mean EMG activity was expressed as a percentage of MVIC for the 6 tested muscles, and these normalized EMG values were used for further analysis.

Statistical Analysis

SPSS Statistics version 22 (IBM Corp) was used to perform all statistical analyses. Means and SDs for normalized SA, UT, MT, LT, BB, and TB EMG activity were calculated for each exercise and across subjects (Table 2). Normalized EMG values were divided into 3 categories based on percentage of MVIC: EMG activity was considered low when <20% MVIC, moderate when between 20% and 50%, and high when >50% MVIC.[9,38] To assess trial-to-trial reliability of the MVIC measurements, intraclass correlation coefficients (ICCs) (2-way random model, type consistency) were calculated. Because BB muscle activity was the variable of interest, further statistical analysis was conducted to determine statistical differences in mean BB activity between the 11 exercises. Because BB muscle activity across exercises was not normally distributed (Shapiro-Wilk), nonparametric tests were used. Therefore, a Friedman test with 11 test variables was conducted to analyze the mean BB activity between the 11 exercises. Alpha value was set at .05. Post hoc pairwise comparisons for BB activity were performed using a Wilcoxon signed-rank test. For pairwise comparison, Bonferroni correction for multiple comparisons was executed.

RESULTS

The ICCs between the 3 attempts of the MVIC for the 5 selected muscles ranged between 0.87 and 0.97. More specifically, ICC was 0.97 for SA ($F = 33.61$; $P < .001$), 0.87 for UT ($F = 7.70$; $P < .001$), 0.94 for MT ($F = 16.59$; $P < .001$), 0.89 for LT ($F = 9.21$; $P < .001$), 0.93 for BB ($F = 14.19$; $P < .001$), and 0.95 for TB ($F = 19.55$; $P < .001$). Means and SDs for the EMG activity of each muscle for the 11 exercises are described in Table 2. In this table, EMG activity was divided into 3 categories (low, moderate, or high) according to percentage of MVIC, which is visualized by the different gray scales. Four exercises showed low activity for the BB: exercise 8 (14.97% MVIC), 1 (16.86% MVIC), 9 (17.26% MVIC), and 2 (18.92% MVIC). Five showed moderate BB activity: exercise 3 (24.06% MVIC), 10 (27.58% MVIC), 6 (35.56% MVIC), 4 (41.96% MVIC), and 5 (43.99% MVIC). Two showed high BB EMG activity: exercise 7 (56.96% MVIC) and 11 (67.37% MVIC). In Figure 2, all 11 exercises are ranked from low to high BB activity (in percentage MVIC). No statistical difference in BB activity between successive exercises was found, and all exercises with low BB activity were not statistically different from each other. Exercise 11, the exercise with the highest EMG activity in the BB, was statistically different from all other exercises except for exercise 7 (the exercise with the second-highest BB activity).

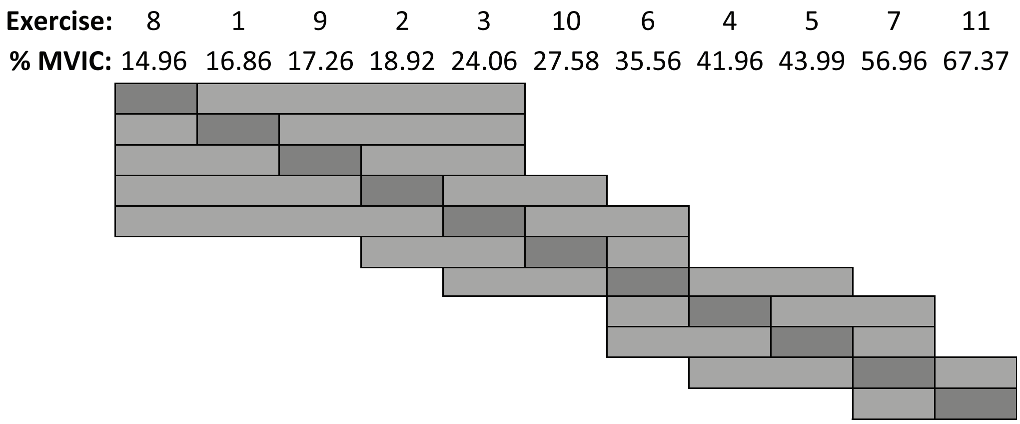

Figure 2. Ranking of all 11 exercises from low to high biceps brachii activity (in percentage maximal voluntary isometric contraction). The exercise of interest is marked in dark gray. Successive exercises without a statistically significant difference from the exercise of interest are marked in light gray.

DISCUSSION

The purpose of this study was to compare EMG activity of the BB during 11 exercises to propose a progression of exercises targeting moderate (20%-50% MVIC) to high (>50% MVIC) BB activity. These 11 exercises were ranked with an increasing level of activity in the BB. In addition, TB and scapulothoracic (UT, MT, LT, and SA) muscle EMG activity was examined during all exercises. This is the first study establishing a continuum of exercises with moderate to high biceps activity, as Cools et al[9] found only exercises with low to moderate activity, which never exceeded 35.9% MVIC. The major finding of this study is that 7 out of 11 exercises show moderate to high BB activity; in 5 out of these 7 exercises, activity exceeded 35% of MVC. This graded exercise program may help the clinician select exercises to be used in the intermediate to advanced phase of nonoperative or postoperative rehabilitation of overhead athletes with biceps-related injuries.

Although all 11 exercises were chosen to target moderate to high BB activity, 4 exercises (1, 2, 8, and 9) showed low activity levels (<20% MVIC). In addition, BB activity was not significantly different between these 4 exercises. For the lateral pull-down (exercises 1 and 2), a supinated grip does not seem to preferably activate the biceps, although a supinated grip (exercise 2) demonstrated a small, nonsignificant increase in biceps activity compared with a pronated grip (exercise 1). This finding is in accordance with previous studies.[34,35] The arm shake (exercise 8) and chest shake (exercise 9) showed EMG activity levels of 14.97% MVIC and 17.26% MVIC, respectively, which is in line with the results of Porcari.[41] However, Glenn et al[22] demonstrated higher BB activity levels of 42.7% for the arm shake and 35.8% MVIC for the chest shake. The differences in BB activity in our study and previously reported results might be explained by the different weights used to perform the exercise.

Exercises 3 (pull-up in pronation) and 10 (air punch) showed moderate BB activity (20%-50% MVIC) but did not exceed the value of 35% MVIC. This value is the highest BB value in the study of Cools et al[9] and is therefore chosen as a reference. Biceps activity levels were higher than 35% MVIC for 5 exercises (exercises 6, 4, 5, 7, and 11); out of these 5 exercises, 3 (exercises 6, 4, and 5) showed moderate and 2 (exercises 7 and 11) showed high activity (>50% MVIC). Based on our study, biceps muscle activity over 35% MVIC can be achieved in 4 different ways. First, the biceps is activated during elevation in the sagittal plane, which is in accordance with the study of Cools et al,[9] who found the highest value in forward flexion in external rotation and supination (35.9% MVIC). The same exercise is repeated in our study (exercise 6) and revealed a similar biceps activity of 35.56% MVIC.

Second, the biceps is activated during muscle-specific movements (elbow flexion with supination), without upper arm support, which is represented by the pull-up in supination with Redcord (exercise 4). In comparison with the same exercise in pronation (exercise 3), BB activity is significantly increased (24.06% MVIC in exercise 3 and 41.96% MVIC in exercise 4). Likewise, Youdas et al[46] examined different pull-up conditions using a portable pull-up device and did find higher (although nonsignificant) BB activity in the supinated grip compared with the pronated grip. In addition, the pull-ups performed with a portable device generated higher BB activity (varying from 78% MVIC to 96% MVIC) than did the pull-ups with Redcord in our study. This might be due to the difference in exercise performance. The pull-ups in the study of Youdas et al[46] were performed in an upright position with both arms in maximal forward flexion instead of an inclined position with the arms in 90° forward flexion as in this study. In addition, the exercises were performed nonweightbearing (90° of knee flexion) in comparison to weightbearing (feet supported) in our study.

Subsequently, biceps activity over 35% can be achieved by functionally contracting the biceps muscle from an elongated position. In exercise 5 (IBC), an elbow flexion with forearm supination is performed with the shoulder in 50° of extension, thus positioning the biceps muscle in an elongated position. This exercise generated higher activity

(43.99% MVIC) in comparison with an elbow flexion in supination with the shoulder in 45° of forward flexion (less elongated position) as presented in the study of Cools et al[9] (34.6% MVIC). In addition, Oliveira et al[39] examined the effect of shoulder position on BB EMG activity in 3 different biceps curls: seated with shoulder in 50° hyperextension (IBC), standing with the arm alongside the body (DBC), and seated with shoulder flexed at 50° (DPC). They suggested that BB activity was affected by shoulder flexion angle since a significant increase in biceps activity was found in the IBC and DBC in comparison with the DPC. Unexpectedly, no significant difference was observed between IBC and DBC. The authors suggested that due to hyperextension in the shoulder during the IBC, the long head of the biceps is elongated beyond its optimal length.

Finally, biceps muscle activity seems to be triggered by high-velocity, explosive exercises as seen in exercises 7 and 11, which elicit high biceps activity. When comparing exercise 7 (throwing forward flexion in 90° with soft weight ball) with exercise 6 (forward flexion in external rotation and forearm supination with dumbbell), a significantly higher biceps activity is found (56.96% compared with 35.56% MVIC). This finding could be explained by the plyometric nature of exercise 7, which is performed at a higher velocity than is exercise 6 (1 s/repetition compared with 6 s/repetition). Furthermore, triceps activity in exercise 7 is the highest of all exercises, suggesting that this plyometric movement generates biceps and triceps co-contraction. Unfortunately, there are no research articles with which to compare our results. Similar to exercise 7, exercise 11 (reverse punch) is a high-velocity movement conducted at 1 repetition/s. This exercise has elicited the highest BB EMG activity (67.37% MVIC) and is the only one that is significantly different from all other exercises with the exception of exercise 7. Our results show that when performing a reverse punch against resistance to elbow flexion and supination (exercise 11), biceps activity will be significantly higher than when conducting a regular punch without resistance (exercise 10). When observing exercise 10, subjects were rather focused on the forward phase of the punch (elbow extension in pronation) than on the reversed phase (elbow flexion in supination). In contrast, subjects' attention was on explosively conducting the reversed phase of the punch in exercise 11, as a result of using an elastic tube for resistance to elbow flexion and supination.

Although this study proposes a progression of exercises, specific guidelines regarding load, velocity, and volume may not be provided based on our results. The clinician should bear in mind that choosing rehabilitation exercises is a multidimensional problem in which exercise selection is only one component.

Regarding scapular muscles, exercises 3, 4, and 11 show high MT and/or LT activity, possibly because they all have a scapular retraction component.[9] Consequently, these exercises are considered to be valuable for rehabilitation of trapezius muscle weakness or imbalance.[10] Furthermore, all 3 exercises elicit moderate to high BB activity and should be used only in the intermediate to advanced phase of rehabilitation for overhead athletes with biceps-related pathologic conditions. In these treatment phases, a sport-specific training approach is often desirable and may be achieved in gymnasts by performing exercises 3 and 4 or in punching-related sports with exercise 11. For initial treatment, exercises with high MT and/or LT activity in combination with low BB activity are preferred, as described by Cools et al.[9]

Concerning SA activity, all but 3 (exercises 5, 8, and 9) demonstrate high SA activity, which is possibly the result of using a high external load during these exercises. When comparing exercise 6 with the same exercise in the study of Cools et al,[9] all EMG values are quite similar except for SA activity, which is higher in our study. The only difference between studies is the weight of the dumbbells, which was higher in our study for both men and women. It would appear that using a higher external load results in a higher SA activity without changing BB activity during this exercise. Other variables should be considered for an increase in biceps activity, such as contracting the biceps muscle in a more elongated position, as displayed in exercise 5. Another possible explanation for the high SA activity in our study is that all these exercises are characterized by a high degree of shoulder forward flexion (90° or more). In exercises 5, 8, and 9, in which the SA is moderately activated, the shoulder is positioned in 50° of extension, 90° of abduction, or 45° of forward flexion, respectively, thus possibly leading to lower SA activity.

The overall moderate to high activity in scapular muscles might also be explained by the moderate to high biceps activity (except for exercises 5 and 8). As the BB attaches to the lateral aspect of the scapula, increased activity levels in scapulothoracic muscles, attaching on the medial, inferior, and superior scapula, would be expected to prevent lateral scapular translation.[30]

LIMITATIONS

Interpretation of the results must be viewed within the limitations of the study. The first limitation is inherent to the use of surface EMG and, more specifically, the validity of using surface electrodes to determine SA activity during dynamic shoulder exercises.[23] Precautions were taken by following the SENIAM prescriptions and by maximal standardization and accuracy.[25] Moreover, our MVIC measurements showed excellent trial-to-trial reliability, with ICCs varying from 0.87 to 0.97. Although biceps muscle activity was the variable of interest in this study, assessment of deeper muscle groups such as the RC is not possible when using surface EMG. Future research needs to explore RC activity using fine-wire electrodes during biceps-targeting exercises since RC muscle weakness is often present in patients with biceps-related disorders. Second, extrapolation of these results to overhead athletes with biceps injuries should be done with caution because our study population consisted of young, healthy subjects. In addition, we did not evaluate the biomechanical stress on the biceps during the exercises. Subsequently, strains, loads, torsional forces at the glenoid superior labrum, and impingement of the biceps tendon should be explored in future research. Finally, outcome studies are needed to determine the effectiveness of this proposed exercise program for the biceps muscle.

CONCLUSION

This is the first study proposing a continuum of exercises with moderate to high biceps activity that may be applied in the intermediate to advanced phases of treatment for proximal biceps-related disorders. The results indicated that biceps muscle activity is targeted by (1) sagittal plane elevation; (2) elbow flexion with supination, without upper arm support; (3) biceps contraction from an elongated position; or (4) high-velocity, explosive exercises. These findings may assist clinicians and coaches in selecting appropriate exercises to be used in the intermediate to advanced phase of nonoperative or postoperative rehabilitation of overhead athletes with biceps-related injuries.

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A Video Supplement for this article is available online.

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