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Rehabilitation Exercises for Athletes With Biceps Disorders and SLAP Lesions

A Continuum of Exercises With Increasing Loads on the Biceps

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Background: Although rehabilitation exercises are recommended in the nonoperative and postoperative treatment of biceps-related disorders and superior labrum anterior-posterior (SLAP) lesions in overhead athletes, a progressive exercise protocol with controlled low to moderate loads on the biceps has not yet been described.

Purpose: To describe a continuum of exercises with progressive low to moderate loads on the biceps based on electromyographic (EMG) analysis.

Study Design: Descriptive laboratory study.

Methods: Using surface electromyography, the EMG activity of 8 muscles (upper [UT], middle [MT], and lower [LT] trapezius; serratus anterior [SA]; anterior [AD] and posterior [PD] portions of the deltoid; and biceps [BB] and triceps [TB] brachii) was measured in 32 healthy participants performing 16 commonly described shoulder rehabilitation exercises.

Results: Of the 16 exercises, 13 (side-lying shoulder forward flexion, prone extension, seated rowing, serratus punch, knee push-up plus, internal and external rotation both in 20° and 90° of abduction, forearm supination, uppercut, and internal and external rotation diagonal) showed low (<20% maximal voluntary isometric contraction [MVIC]) EMG activity in the BB, and 3 (forward flexion in supination, full can, and elbow flexion in forearm supination) showed moderate (20%-50% MVIC) activity. None of the exercises elicited high (>50% MVIC) EMG activity. Based on the results, a ranking was calculated of the exercises, with mean EMG levels between 2.2% ± 1.24% (during internal rotation against resistance in 90° of shoulder abduction) and 35.9% ± 18.82% (during forward flexion in external rotation and supination) of MVIC.

Conclusion: This study describes a continuum of exercises with an increasing level of EMG activity in the BB. Exercises targeting the trapezius resulted in less loads on the biceps compared with exercises for the SA. In addition, exercises with an internal rotation component showed low activity in the BB. In general, the exercises meant to target the BB showed the highest levels of activity in the BB.

Clinical Relevance: These results may assist the clinician in the appropriate choice of exercises in a graded rehabilitation program of biceps-related injuries.

Keywords: biceps pathological disorders; SLAP lesions; rehabilitation; electromyography
In general, repetitive overhead activity has been hypothesized as a common mechanism for producing biceps-related shoulder pathological abnormalities. Both the long and short head of the biceps play an important role in functional shoulder stability, although their function differs based on their origin. Whereas the short head is a scapulohumeral muscle, the long head can be considered to be a glenohumeral muscle. Although the pathomechanism is debated, the torsional compressive force on the origin of the long head of the biceps during the cocking position, as well as the high eccentric activity of the biceps muscle during the follow-through phase of throwing, and the impingement of the biceps tendon underneath the acromial arch during overhead activities are believed to possibly cause irritation, dysfunction, and failure of the superior labral and biceps tendon complex.

Recent clinical guidelines have suggested that the vast majority of overhead athletes with shoulder pain should be initially treated with nonoperative methods. Only certain diagnoses, such as traumatic injuries with documented structural damage such as dislocations or rotator cuff tears, may warrant earlier and more aggressive operative intervention. Several guidelines containing a phased progression of rehabilitation have been published for the nonoperative management of shoulder pain in overhead-throwing athletes. These programs consist of stretching and strengthening exercises for the shoulder girdle, the trunk, and the lower extremities. In cases of biceps-related shoulder pain, the authors suggest limited and controlled tension and loading on the biceps.

Restoring passive shoulder internal rotation range of motion and graded strengthening of the scapular muscles and the rotator cuff are considered to be key components of a nonoperative training program to prepare the athlete for return to play. In addition, in postoperative rehabilitation programs after SLAP repair, biceps activity needs to be controlled during the first 12 weeks after surgery, with no resisted biceps activity during the first 8 weeks to protect the healing of the biceps anchor and no aggressive strengthening of the biceps for 12 weeks after surgery.

Numerous studies have highlighted the importance of appropriate exercise choices based on electromyographic (EMG) analysis of the targeted muscles. Most literature regarding the EMG activity of shoulder exercises has focused on which exercises activate specific rotator cuff or scapular muscles primarily during a specific exercise or activate them synergistically in a scapular force couple. However, the literature regarding biceps activation during selected rehabilitation exercises of the rotator cuff and scapular muscles is scarce. Myers et al registered between 5.5% (during a throwing acceleration exercise) and 22.1% (during a shoulder flexion exercise) of maximal voluntary isometric contraction (MVIC) using elastic tubing equipment. Studies examining biceps activity during axial-load closed chain exercises revealed very low levels of activity during the push-up position as well as the wall-press position. In summary, there is very limited evidence of the loads on the biceps during commonly used rehabilitation exercises. Moreover, in the rehabilitation of pathological changes of the long head of the biceps and SLAP lesions, caution is warranted regarding muscle activation of the biceps in view of tissue protection and healing, and graded progressive loading on the muscle is crucial during the rehabilitation process.

Therefore, the purpose of this study was to investigate the EMG activity of the biceps in conjunction with scapulothoracic and glenohumeral muscles during a series of commonly used rehabilitation exercises and propose a ranking of the exercises based on biceps activity, intended to be used as a continuum of exercises during the rehabilitation of the overhead athlete with biceps-related shoulder pain. We hypothesized that, from a sample of commonly used rehabilitation exercises, a number of exercises may be extracted with low (<20% MVIC), moderate (20%-50% MVIC), and high (>50% MVIC) activity in the biceps brachii.

MATERIALS AND METHODS

Participants

Thirty-two healthy volunteers (16 men, 16 women) participated in this study. The mean (±standard deviation) age was 22.3 ± 1.3 years, mean height was 1.75 ± 0.098 m, mean weight was 67.8 ± 10.29 kg, and mean body mass index was 22.0 ± 2.11 kg/m². Exclusion criteria for participation in the study were a history of cervical spine and shoulder injury or surgery, participation in overhead sports at a competitive level, and upper limb strength training for more than 5 h/wk. Inclusion and exclusion criteria were assessed with a questionnaire. Before participation, participants read and signed the informed consent form. The investigation was approved by the ethics committee of Ghent University.

Instrumentation

Before electrode application, the skin was shaved if necessary and prepared with alcohol to reduce skin impedance (typically, <10 kΩ). Bipolar surface electrodes (Ambu Blue Sensor P, Ambu A/S, Ballerup, Denmark) were placed with a 2-cm interelectrode distance over the upper (UT), middle (MT), and lower (LT) portions of the trapezius; the serratus anterior (SA); the anterior (AD) and posterior (PD) portions of the deltoid; and the muscle belly of the biceps (BB) and triceps (TB) brachii according to the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) Project recommendations (Table 1). A reference electrode was placed over the clavicle. In all of the participants, the dominant arm was tested. Each set of bipolar recording electrodes from each of 8 muscles was connected to a Myosystem 2000 EMG receiver (Noraxon Inc, Scottsdale, Arizona, USA). The sampling rate was 1000 Hz. All raw myoelectric signals were preamplified (overall gain, 1000; common rate rejection ratio.
115 dB; signal-to-noise ratio <1 μV root mean square (RMS) baseline noise, filtered to produce a bandwidth of 10-1000 Hz).

Exercise Selection

Sixteen commonly used shoulder rehabilitation exercises were chosen on the basis of several EMG studies and clinical recommendations regarding the rehabilitation of patients with SLAP lesions. The exercises are (1) forward flexion in a side-lying position, (2) prone extension, (3) seated rowing, (4) serratus punch (protraction with the elbow extended), (5) knee push-up plus, (6) forward flexion in external rotation and forearm supination, (7) full can (elevation in the scapular plane in external rotation), (8) internal rotation in 20° of abduction, (9) external rotation in 20° of abduction, (10) internal rotation in 90° of abduction, (11) external rotation in 90° of abduction, (12) forearm supination, (13) elbow flexion in forearm supination, (14) uppercut (combined forward flexion of the shoulder and flexion and supination of the elbow), (15) internal rotation diagonal, and (16) external rotation diagonal. The 16 exercises are described in Table 2 and are illustrated in Appendix 1 (available in the online version of this article at http://ajsm.sagepub.com/supplemental).

Testing Procedure

Each participant performed a series of 16 exercises with the dominant arm. Series were randomized to avoid systematic fatigue influences. Before data collection, all exercises were demonstrated by the investigator and exercised without resistance by the participant for reasons of familiarization with the protocol. After a warm-up procedure with multidirectional shoulder movements, the myoelectric resting level of each muscle was recorded. Then, the MVIC was determined in manual muscle test positions specific to each muscle of interest. For the UT, resistance was applied to 90° of abduction. For the MT, performed in a prone position, resistance was applied to horizontal abduction in glenohumeral external rotation. The LT was tested in a prone position by applying resistance to maximal elevation in the arm in line with the muscle fibers. The SA was tested by applying resistance to 135° of elevation in a seated position. For the AD and PD, resistance was applied on the distal aspect of the humerus to forward flexion and arm extension, respectively. For the BB and TB, resistance was applied to 90° of elbow flexion and elbow extension, respectively. Participants performed three 5-second MVICs with a 15-second pause between muscle contractions. Then, 5 repetitions of each exercise were completed. Each exercise was performed in a concentric, isometric, and eccentric phase, with each phase lasting 3 seconds. A 5-second pause was provided between each trial. A resting period of 2 minutes was allowed between exercises. Exercises were verbally encouraged. A metronome was used to control the duration of the contraction. The amount of weight used by the participants was determined based on sex and body weight based on a 10-repetition maximum9,15 (Appendix 2, available online).

Data Processing

MyoResearch XP Master Edition (Noraxon Inc) was used for signal processing. All raw EMG signals were analog/digital converted (12-bit resolution) at 1000 Hz. After cardiac artifact reduction, EMG signals were fully wave rectified and smoothed (RMS, 100 ms). The EMG values during the exercises were normalized to the maximum activity measured during the MVIC trials. The EMG data for each muscle and each participant were averaged for each phase across the 3 intermediate repetitions of the 5 repetitions completed. The first and fifth repetitions were not used to avoid any distortion due to habituation and fatigue. Periods were defined by markers based on the 3-second phases of the exercises. The markers were set by synchronizing the metronome with the EMG registration. One-second markers were automatically placed on the EMG signal based on the metronome sound. The mean EMG signal amplitude, expressed as a percentage of MVIC, was used to assess the activity of the 8 muscles of interest.

Statistical Analysis

The a priori power analysis for this study was set at 80%, based on an α level of .05, resulting in a minimal sample size of 30. Means ± standard deviations were calculated across participants for the normalized EMG values (in %

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TABLE 1
Electrode Placement According to the SENIAM Project Recommendations

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Placement Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT</td>
<td>Midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius</td>
</tr>
<tr>
<td>MT</td>
<td>Midway on a horizontal line between the root of the spine of the acromion and the third thoracic spine</td>
</tr>
<tr>
<td>LT</td>
<td>Obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process</td>
</tr>
<tr>
<td>SA</td>
<td>Parallel to the muscle fibers, below the axilla, anterior to the latissimus dorsi, and posterior to the pectoralis major</td>
</tr>
<tr>
<td>AD</td>
<td>One-finger width distal and anterior to the acromion</td>
</tr>
<tr>
<td>PD</td>
<td>Two-finger widths distal to the posterior angle of the acromion</td>
</tr>
<tr>
<td>BB</td>
<td>Anteriorly two thirds of the distance between the acromion and the cubital groove</td>
</tr>
<tr>
<td>TB</td>
<td>Posterily midway between the acromion and the olecranon</td>
</tr>
</tbody>
</table>

*AD, anterior portion of the deltoid; BB, biceps brachii; LT, lower trapezius; MT, middle trapezius; PD, posterior portion of the deltoid; SA, serratus anterior; SENIAM, Surface Electromyography for the Non-Invasive Assessment of Muscles; TB, triceps brachii; UT, upper trapezius.

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References 9, 12, 15, 20, 27, 28, 30-33, 38.
TABLE 2
Description of the 16 Exercises Performed by the Study Participants, With Their Main Training Target*

<table>
<thead>
<tr>
<th>No.</th>
<th>Exercise</th>
<th>Material</th>
<th>Description</th>
<th>Target Muscle Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Forward flexion in side-lying position*</td>
<td>Dumbbell</td>
<td>Participant in a side-lying position, with the shoulder in neutral position; participant performs forward flexion in a horizontal plane up to 90°.</td>
<td>ST</td>
</tr>
<tr>
<td>2</td>
<td>Prone extension*</td>
<td>Dumbbell</td>
<td>Participant prone, with shoulders resting in 90° of forward flexion; participant performs extension to neutral position with the shoulder in a neutral rotational position.</td>
<td>ST</td>
</tr>
<tr>
<td>3</td>
<td>Seated rowing*</td>
<td>Pulley apparatus with 2 handles</td>
<td>Participant sitting in front of the pulley apparatus, with shoulders in 90° of forward flexion and neutral rotation; participant performs shoulder extension with elbows flexed.</td>
<td>ST</td>
</tr>
<tr>
<td>4</td>
<td>Serratus punch*</td>
<td>Pulley apparatus</td>
<td>Participant standing with his back to the pulley apparatus, with the shoulder in 90° of forward flexion and neutral rotation; participant performs scapular protraction with elbow extended.</td>
<td>ST</td>
</tr>
<tr>
<td>5</td>
<td>Knee push-up plus 12</td>
<td>Body weight</td>
<td>Participant in 4-point kneeling position, with body weight supported by hands and knees; participant performs a push-up with scapular protraction.</td>
<td>ST</td>
</tr>
<tr>
<td>6</td>
<td>Forward flexion in external rotation and forearm supination*</td>
<td>Dumbbell</td>
<td>Participant standing, with the arm at the side in external rotation and forearm supination; participant performs forward flexion in a sagittal plane to 90°.</td>
<td>ST, GH</td>
</tr>
<tr>
<td>7</td>
<td>Full can*</td>
<td>Dumbbell</td>
<td>Participant standing, with the arm at the side in external rotation; participant performs forward flexion in the scapular plane (30° anterior of the frontal plane) to 90°.</td>
<td>ST, GH</td>
</tr>
<tr>
<td>8</td>
<td>Internal rotation of abduction*</td>
<td>Pulley apparatus</td>
<td>Participant sitting, with the arm supported in external rotation in 20° of abduction; participant performs internal rotation with elbow flexed 90°.</td>
<td>GH</td>
</tr>
<tr>
<td>9</td>
<td>External rotation of abduction*</td>
<td>Pulley apparatus</td>
<td>Participant sitting, with the arm supported in internal rotation in 20° of abduction; participant performs external rotation with elbow flexed 90°.</td>
<td>GH</td>
</tr>
<tr>
<td>10</td>
<td>Internal rotation of abduction*</td>
<td>Pulley apparatus</td>
<td>Participant sitting, with the arm supported in external rotation in 90° of abduction; participant performs internal rotation with elbow flexed 90°.</td>
<td>GH</td>
</tr>
<tr>
<td>11</td>
<td>External rotation of abduction*</td>
<td>Pulley apparatus</td>
<td>Participant sitting, with the arm supported in internal rotation in 90° of abduction; participant performs maximal external rotation with elbow flexed 90°.</td>
<td>GH</td>
</tr>
<tr>
<td>12</td>
<td>Forearm supination*</td>
<td>Pulley apparatus with bar</td>
<td>Participant sitting, with the arm supported in 45° of forward flexion and 90° of elbow flexion with forearm pronation; participant performs supination.</td>
<td>BB</td>
</tr>
<tr>
<td>13</td>
<td>Elbow flexion in forearm supination*</td>
<td>Pulley apparatus</td>
<td>Participant sitting, with the arm supported in 45° of forward flexion and 90° of elbow flexion with forearm pronation; participant performs supination; participant performs elbow flexion.</td>
<td>BB</td>
</tr>
<tr>
<td>14</td>
<td>Uppercut*</td>
<td>Dumbbell</td>
<td>Participant standing, with the arm at the side in forearm pronation; participant performs 90° of forward flexion, 90° of elbow flexion, and maximal supination at the same time.</td>
<td>BB, CM</td>
</tr>
<tr>
<td>15</td>
<td>Internal rotation diagonal*</td>
<td>Pulley apparatus</td>
<td>Participant standing, with the homolateral side to the pulley apparatus, arm in 90° of abduction, maximal external rotation, and 90° of elbow flexion; participant moves the arm across the body toward the heterolateral hip.</td>
<td>CM</td>
</tr>
<tr>
<td>16</td>
<td>External rotation diagonal*</td>
<td>Pulley apparatus</td>
<td>Participant standing, with the heterolateral side to the pulley apparatus, arm in adduction, internal rotation, and 90° of elbow flexion and the hand at the heterolateral hip; participant performs forward flexion, 90° of abduction, and 90° of external rotation.</td>
<td>CM</td>
</tr>
</tbody>
</table>

*BB, biceps training; CM, combined movements; GH, glenohumeral muscle training; ST, scapulothoracic muscle training.

of MVIC) of the UT, MT, LT, SA, AD, PD, BB, and TB for each of the 3 phases of the 16 exercises. To reduce redundancy of data, and in view of the research question, data from all 3 phases (concentric, isometric, and eccentric) were averaged, resulting in a single value for each muscle per exercise. Because all data were normally distributed
EMG Activity of Each Muscle for the 16 Exercises (in % MVIC)\(^a\)

<table>
<thead>
<tr>
<th>No.</th>
<th>UT</th>
<th>MT</th>
<th>LT</th>
<th>SA</th>
<th>AD</th>
<th>PD</th>
<th>BB</th>
<th>TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.7 ± 11.09</td>
<td>87.3 ± 45.37</td>
<td>76.6 ± 38.66</td>
<td>10.3 ± 9.41</td>
<td>43.4 ± 22.21</td>
<td>125.6 ± 66.40</td>
<td>9.7 ± 6.18</td>
<td>33.8 ± 17.49</td>
</tr>
<tr>
<td>2</td>
<td>17.1 ± 11.54</td>
<td>36.1 ± 15.32</td>
<td>28.6 ± 34.56</td>
<td>10.3 ± 6.44</td>
<td>7.8 ± 4.14</td>
<td>64.6 ± 21.69</td>
<td>4.2 ± 2.05</td>
<td>50.1 ± 16.65</td>
</tr>
<tr>
<td>3</td>
<td>14.2 ± 11.20</td>
<td>23.1 ± 12.50</td>
<td>14.8 ± 19.66</td>
<td>4.1 ± 3.12</td>
<td>7.3 ± 4.56</td>
<td>31.0 ± 14.84</td>
<td>5.8 ± 4.61</td>
<td>8.9 ± 6.02</td>
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<tr>
<td>4</td>
<td>8.9 ± 6.81</td>
<td>6.0 ± 3.35</td>
<td>5.9 ± 4.00</td>
<td>42.7 ± 15.49</td>
<td>53.2 ± 25.09</td>
<td>12.2 ± 10.60</td>
<td>8.9 ± 7.49</td>
<td>16.3 ± 7.69</td>
</tr>
<tr>
<td>5</td>
<td>11.5 ± 5.17</td>
<td>10.2 ± 5.71</td>
<td>8.5 ± 5.60</td>
<td>37.0 ± 18.12</td>
<td>41.2 ± 20.12</td>
<td>8.3 ± 5.83</td>
<td>4.8 ± 3.15</td>
<td>10.5 ± 12.72</td>
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<tr>
<td>6</td>
<td>48.2 ± 22.42</td>
<td>31.3 ± 15.68</td>
<td>41.0 ± 24.04</td>
<td>68.9 ± 16.85</td>
<td>107.9 ± 44.97</td>
<td>17.8 ± 10.50</td>
<td>35.9 ± 18.82</td>
<td>15.7 ± 8.05</td>
</tr>
<tr>
<td>7</td>
<td>55.2 ± 22.74</td>
<td>45.4 ± 17.09</td>
<td>45.2 ± 27.31</td>
<td>58.1 ± 14.88</td>
<td>106.4 ± 39.32</td>
<td>27.5 ± 18.61</td>
<td>29.0 ± 16.69</td>
<td>16.0 ± 10.76</td>
</tr>
<tr>
<td>8</td>
<td>2.7 ± 1.99</td>
<td>3.2 ± 1.99</td>
<td>4.2 ± 2.17</td>
<td>9.4 ± 5.49</td>
<td>15.7 ± 12.36</td>
<td>2.0 ± 1.55</td>
<td>6.2 ± 3.51</td>
<td>5.9 ± 4.43</td>
</tr>
<tr>
<td>9</td>
<td>22.3 ± 12.09</td>
<td>17.5 ± 25.05</td>
<td>7.3 ± 4.67</td>
<td>13.3 ± 8.97</td>
<td>11.4 ± 7.27</td>
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<td>3.0 ± 1.82</td>
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<td>4.3 ± 3.90</td>
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<td>23.7 ± 9.93</td>
<td>44.6 ± 40.07</td>
<td>74.9 ± 56.26</td>
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<td>13.7 ± 18.04</td>
<td>28.6 ± 23.85</td>
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<td>12</td>
<td>4.7 ± 3.39</td>
<td>11.8 ± 11.08</td>
<td>20.6 ± 18.88</td>
<td>5.8 ± 4.10</td>
<td>4.1 ± 2.45</td>
<td>19.4 ± 14.34</td>
<td>15.4 ± 7.19</td>
<td>18.7 ± 12.67</td>
</tr>
<tr>
<td>13</td>
<td>2.9 ± 2.00</td>
<td>7.2 ± 6.44</td>
<td>21.7 ± 17.78</td>
<td>8.1 ± 5.07</td>
<td>10.8 ± 9.23</td>
<td>5.6 ± 3.31</td>
<td>34.6 ± 15.91</td>
<td>10.3 ± 5.72</td>
</tr>
<tr>
<td>14</td>
<td>33.0 ± 19.20</td>
<td>20.2 ± 10.99</td>
<td>32.5 ± 19.65</td>
<td>47.9 ± 14.01</td>
<td>80.5 ± 32.36</td>
<td>11.1 ± 6.20</td>
<td>19.3 ± 10.06</td>
<td>9.7 ± 5.90</td>
</tr>
<tr>
<td>15</td>
<td>7.9 ± 5.29</td>
<td>6.4 ± 4.69</td>
<td>6.0 ± 4.86</td>
<td>15.0 ± 8.93</td>
<td>14.0 ± 11.56</td>
<td>5.8 ± 3.61</td>
<td>7.9 ± 4.63</td>
<td>14.7 ± 6.73</td>
</tr>
<tr>
<td>16</td>
<td>43.6 ± 21.14</td>
<td>48.7 ± 16.48</td>
<td>55.8 ± 30.34</td>
<td>48.0 ± 17.09</td>
<td>53.2 ± 23.16</td>
<td>41.3 ± 23.35</td>
<td>12.7 ± 5.40</td>
<td>16.4 ± 9.97</td>
</tr>
</tbody>
</table>

\(^a\)Data (mean ± standard deviation) are graded and visually represented according to the percentage of maximal voluntary isometric contraction (MVIC): low, <20% MVIC (light gray); moderate, 20%-50% MVIC (medium gray); and high, >50% MVIC (dark gray). AD, anterior portion of the deltoid; BB, biceps brachii; EMG, electromyographic; LT, lower trapezius; MT, middle trapezius; PD, posterior portion of the deltoid; SA, serratus anterior; TB, triceps brachii; UT, upper trapezius.

RESULTS

Means ± standard deviations were calculated across all participants for each muscle in each exercise and graded according to low, moderate, or high activity (Table 3). The mean ICCs between 3 MVIC repetitions were 0.98 for the UT (F = 44.78; P < .001), 0.96 for the MT (F = 25.15; P < .001), 0.98 for the LT (F = 43.73; P < .001), 0.98 for the SA (F = 46.20; P < .001), 0.93 for the AD (F = 15.05; P < .001), 0.96 for the PD (F = 26.86; P < .001), 0.96 for the BB (F = 26.26; P < .001), and 0.96 for the TB (F = 27.69; P < .001). The ANOVA model revealed that sphericity could not be assumed, and a Greenhouse-Geisser correction was used to interpret all results. The general linear model ANOVA for repeated measures showed significant main effects for exercise (F = 58.81; P < .001). Post hoc pairwise comparisons with Bonferroni correction exhibited statistical differences among exercises (Appendix 3, available online). Because of clinical utility, the 16 exercises were then ranked according to the percentage of MVIC of the BB and visualized in Figure 1. Successive exercises did not show any statistical differences, with the exception of exercise 10, which exhibited a lower EMG value than those of all other exercises. No exercise showed high EMG activity of the BB (>50% MVIC). Exercises 6 (35.9% MVIC), 7 (29.0% MVIC), and 13 (34.6% MVIC) showed moderate activity but did not significantly differ from each other. All other exercises exhibited low EMG activity of the BB (<20% MVIC). Furthermore, no statistical difference was observed between exercise 7 with moderate activity and exercise 14 with low activity of the BB (mean difference, 9.7% MVIC; P = .137).

DISCUSSION

The purpose of this investigation was to describe a continuum of exercises, which were selected based on their common use in the rehabilitation of shoulder pain in the overhead athlete, with an increasing level of EMG activity in the BB. By ranking the exercises based on the activity of the biceps, we are the first researchers presenting a graded exercise program focusing on loads on the biceps muscle and tendon complex and indirectly on the superior labral complex of the glenohumeral joint. This proposal of an exercise program may help the clinician in choosing an exercise in the nonoperative and postoperative...
rehabilitation of overhead athletes with proximal biceps tendon injuries and SLAP lesions.

The results of our study support the hypothesis that, from a sample of commonly used rehabilitation exercises, a number of exercises may be extracted with low (<20% MVIC) activity in the BB, with others showing moderate activity (20%-50% MVIC). No exercise, selected in this investigation, revealed high (>50% MVIC) activity in the BB.

In this study, exercises were selected based on their common use in (1) scapular muscle training, (2) rotator cuff training (internal and external rotation of the shoulder), and (3) biceps-targeted exercises. In the section below, our results are discussed in view of all 3 treatment goals.

Scapular Muscle Training Exercises

Based on the results of this study, exercises 1, 9, 11, and 16 elicited high activity in the LT and/or MT and are considered beneficial for restoring muscle strength and balance in the trapezius.10 All but 1 (exercise 1) have an external rotation component, thus highlighting the importance of combined external rotation–scapular retraction movements in the shoulder to enhance muscle performance in the posterior chain of the shoulder girdle.19,23 In addition, exercise 1 was selected in a study by Cools et al9 for optimal scapular muscle restoration in patients with hyperactivity in the UT and strength and activity deficits in the LT and MT. All the above-mentioned exercises are thus considered to be beneficial in the rehabilitation of trapezius weakness and imbalance. Biceps activity during these exercises was between 8.2% and 12.7% of MVIC. Concerning exercises for the SA, high activity levels in the SA muscle (>50% MVIC) were found during exercises 6 and 7. During these exercises, BB activity comprised 35.9% and 29.0% of MVIC, respectively. We can conclude that, based on the results of this study, exercises targeting the trapezius result in less loads on the biceps muscle compared with exercises for the SA and perhaps for that reason might be preferred before SA training in patients with biceps-related pathological lesions. In view of the typical hyperactivity of the UT in patients with shoulder pain,8,26 and the clinician’s attempt to inhibit activity of that muscle during rehabilitation exercises, it should be noted that all but 1 exercise (exercise 7) showed moderate to low activity in the UT. In cases of UT hyperactivity or trapezius myalgia, the clinician might even choose exercises with low (<20% MVIC) UT activity based on the results of this study, as mentioned in Table 3.

Rotator Cuff Training Exercises

In this study, exercises with an internal rotation component all showed low activity in the BB. Exercises 8, 10, and 15 (progressive internal rotation in neutral position, 90° of abduction, and in a functional diagonal pattern) were characterized by EMG activity levels between 2.2% and 7.9% of MVIC and thus impose minimal loads on the biceps. However, the clinician should bear in mind that only muscular activity was measured in this study by means of EMG analysis, and we have no information on possible mechanical loading or encroachment of the biceps tendon during these exercises. In particular, in a position of 90° of abduction and external rotation (the starting position of exercises 10 and 15), it has been suggested that the biceps tendon is susceptible to impingement underneath the acromial arch and at its insertion on the superior labrum.22 Therefore, the clinician should take into account the above-mentioned risks for impingement when applying these exercises in a rehabilitation protocol for biceps-based...
disorders and shoulder pain, in spite of the low EMG activity levels in the BB.

Exercises focusing on external rotation strength training (exercises 9, 11, and 16) all show low BB activity but slightly higher than the internal rotation exercises, as mentioned above. The EMG activity varies from 8.2% of MVIC (exercise 9) to 12.7% of MVIC (exercise 16). The same considerations, however, should be taken regarding the position of the shoulder in exercises 11 and 16, placing the arm in a position similar to throwing and thus increasing the risk for tendon and labrum compression and irritation.22 Although these exercises have a slightly increased activity level in the BB compared with the internal rotation exercises, they might be favored over the internal rotation exercises because of their clinical relevance. Indeed, overhead athletes often display reduced external rotation strength, which has been identified as a risk factor for throwing-related shoulder pain in a population of professional baseball pitchers.7 In addition, there is some evidence showing beneficial effects of external rotation training to reduce subacromial pressure, thus decreasing the risk for subacromial impingement.41

Biceps-Targeted Exercises

In general, the exercises meant to target the BB (exercises 12, 13, and 14), together with the full can (exercise 7) and forward flexion in external rotation and supination (exercise 6), showed the highest levels of activity in the BB among the exercises, varying between 15.4% and 35.9% of MVIC. Only 3 exercises (exercises 6, 7, and 13) met the criteria of “moderate” activity level (20%-50% MVIC). We can conclude that, based on our results, the biceps is indeed activated during the movements specific for the muscle based on its anatomy and function (elbow flexion and forearm supination) and during elevation in the sagittal and scapular planes. However, based on our results, the EMG activity and thus indirectly the loads on the muscle are never considered to be “high” (>50% MVIC). These findings might be explained by the moderate external loads during the exercises (Appendix 2) and the fact that all exercises were performed in a concentric-eccentric mode in which the amount of external loads is based on what the participant can perform in a concentric mode. Possibly, exercises with an eccentric focus or plyometric emphasis might elicit higher EMG activity in the targeted muscle group. However, this was not studied in our investigation and should be considered as a follow-up research project.

There are very limited data in the literature with which to compare our results. Only a few authors examined BB activity during shoulder rehabilitation exercises.16,32,39 Moreover, these authors did not consider the biceps muscle activity as their primary research and outcome measure. de Oliveira et al16 and Tucci et al39 studied the activation of, among others, the biceps during unilateral wall- and bench-press isometric tasks and found activity levels in the same low range (<10% MVIC) as was found in the protraction exercises (exercises 4 and 5) in our study. Myers et al12 conducted an EMG study examining on-the-field resistance tubing exercises for throwers and described the forward flexion movement to be the most effective in facilitating activation of the BB, with mean EMG levels of 22.1% ± 15.4% of MVIC. This finding was confirmed by our study because we found the highest EMG levels in the BB during elevation in the scapular plane (29.0% ± 16.69% MVIC) and in the sagittal plane with the arm in external rotation and forearm supination (35.9% ± 18.82% MVIC).

Some limitations of our investigation should be noted. The use of surface electromyography during dynamic movements has been a topic of discussion in the literature regarding skin displacement, movement artifacts, influences of contraction modalities on the EMG signals, and normalization methods.14 In addition, it did not allow us to include deeper muscle groups such as the rotator cuff. In general, systematic control of all interfering factors during the test is recommended to obtain reliable EMG data in a noninvasive manner. On the basis of these recommendations, our investigation was executed with maximal standardization and accuracy. Moreover, our MVIC outcome measurements showed excellent trial-to-trial reliability with ICCs varying from 0.93 to 0.98.

From a clinical point of view, the major limitation of our study can be found in the outcome itself. Indeed, in all exercises examined, the EMG activity of the BB never exceeded the level of 35.9% of MVIC, thus never meeting the criteria for “high” activity, reaching 50% of MVIC and more. In general, a level of 50% is considered to be the criterion to enhance muscle endurance and strength of a muscle.32,38 As a result of this limitation, this continuum of exercises should rather be used in the early and intermediate stages of rehabilitation of biceps-related pathological lesions in which the tendon and labrum need to be protected against excessive loads and strains. In the advanced stages of rehabilitation, when strength training of the biceps becomes a specific treatment goal, plyometric and eccentric exercises should be performed. Future studies, however, need to examine EMG activity in the BB during these kinds of exercises, with subdivision of muscle activity for each kind of contraction (concentric vs eccentric) during the exercises. In addition, in the future, the biomechanical loading of the biceps during rehabilitation exercises, by means of strains and torsional forces, and possible impingement of the tendon against the bony glenohumeral structures should be explored. In addition, the EMG activity should be explored in those active in overhead sports activities to extrapolate our results to overhead athletes, who are often confronted with biceps-related pathological abnormalities.

In conclusion, we have provided, based on EMG analysis of the BB during commonly used rehabilitation exercises, recommendations to assist clinicians, coaches, and overhead athletes in deciding which exercises may be better suited for their rehabilitation program for biceps-related pathological disorders. This article proposes a continuum of exercises with increasing low to moderate activity in the BB, which may be applied in the early and intermediate phases of nonoperative and postoperative treatment for patients with proximal biceps tendon disorders and SLAP lesions.
REFERENCES


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