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The different role of each head of the triceps brachii muscle in elbow extension

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A B S T R A C T

Objective: The aim of this study was to investigate the functional role of each head of the triceps brachii muscle, depending on the angle of shoulder elevation, and to compare each muscle force and activity by using a virtual biomechanical simulator and surface electromyography.
Methods: Ten healthy participants (8 males and 2 females) were included in this study. The mean age was 29.2 years (23–45). Each participant performed elbow extension tasks in five different degrees (0, 45, 90, 135, and 180°) of shoulder elevation with three repetitions. Kinematics data and surface electromyography signal of each head of the triceps brachii were recorded. Recorded kinematics data were then applied to an inverse kinematics musculoskeletal modeling software function (OpenSim) to analyze the triceps brachii's muscle force. Correlation between muscle force, muscle activity, elbow extension, and shoulder elevation angle were compared and analyzed for each head of triceps brachii.
Results: At 0° shoulder elevation, the long head of the triceps brachii generates a significantly higher muscle force and muscle activation than the lateral and medial heads ($p < 0.05$). While at 90°, 135° and 180° shoulder elevation, the medial head of the triceps brachii showed a significantly higher muscle force than the long and the lateral heads ($p < 0.05$).
Conclusions: Each head of the triceps brachii has a different pattern of force and activity during different shoulder elevations. The long head contributes to elbow extension more at shoulder elevation and the medial head takes over at 90° and above of shoulder elevation. This study provides further understanding of triceps brachii's for clinicians and health trainers who need to investigate the functional role of the triceps brachii in detail.

Introduction

The triceps Brachii (TB) is a powerful extensor muscle of the upper extremity.[1] It has been described as a single muscle unit with three heads (medial, lateral, and long heads),[2] and a cadaver study found that the medial head of the TB was attached to the olecranon by a deeper separated tendon than the other heads.[3] Different fatigue rates between each head were also observed in a hand grip task during an elbow extension.[4] Hence, it is important to define the role of each TB head.

Biomechanical simulation allows us to investigate the function of a muscle by observing its properties during a particular movement. OpenSim is an open-source inverse kinematics musculoskeletal modeling software for both the development and analysis of dynamic simulations of human movement (Stanford, California, USA). OpenSim has been widely used to analyze muscle force of both the upper and lower limbs, musculoskeletal geometry (such as muscle length) and muscle-tendon properties on these forces[5–11]; it has been validated for biomechanical simulator purposes.[12] Muscle force always produces electrical activity, which can be recorded with an sEMG and serve as an objective parameter to support biomechanical simulation.[13–15]

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One study for triceps muscle and its sEMG activity has been published previously,[16] but the authors only analyzed sEMG activity for repetitive isometric contractions on the heads of the TB and showed the electrical activity of the muscle for its physiological state without kinematics data for its functionality. However, by using inverse kinematics and the sEMG parameter concurrently, we can observe both physiology (muscle activation) and kinematics (muscle force and length) as a unit entity. To our knowledge, no study has assessed the role of each of the heads of the TB using both parameters simultaneously. Therefore, the aim of the present study was to investigate the functional role of each head of the TB by comparing its muscle force and activity during various shoulder elevations. We hypothesized that each head of the TB will have a different force and activity pattern during various shoulder elevation angles. Hence, the muscle's integrity and functional insufficiency can be assessed during physical examination. In addition, this method would also be helpful for athletes to optimize TB training.

Materials and methods

Ten young healthy volunteers with no history of elbow and shoulder pain or disabilities (8 males and 2 females, age range: 23–45, mean: 29.2 years) participated in this study. There was no range of motion (ROM) limitation for any participant. Each participant was required to perform active elbow extension tasks at five different angles of shoulder elevation; 0°, 45°, 90°, 135°, and 180° (Fig. 1). Participants performed 3 repetitions of elbow extension with their dominant right arm for each task, with a minute interval between repetitions to reduce muscle fatigue. The data recording sessions were started after synchronizing the participants' motion to the metronome. Elbow kinematics and triceps head muscle activation were recorded simultaneously.

Muscle force and length measurement

The participant's kinematics data were measured using BioNomadix® wireless Tri-axial Accelerometer (BN-ACCL3 Receiver + Transmitter, Biopac Systems Inc., CA) prior to muscle force measurement. An accelerometer sensor with a 2000 Hz sampling rate was attached to the participant's wrist with adjustable straps. Elbow angles were derived from the angle of vector between the reference position (maximum elbow extension at each shoulder elevation) and the relative position of the accelerometer during each task.

Measured elbow kinematics were then applied to an adapted OpenSim model of the upper limb, which was derived from the Stanford VA Upper Extremity Dynamic Model[17] (Fig. 1). The model consists of rigid bodies representing the trunk, upper arm, forearm, and hand and it was constrained to allow trunk lean, three degrees of freedom at the glenohumeral joint, and flexion/extension at the elbow joint. The actuator set comprised 29 muscles crossing the glenohumeral and elbow joints. Muscle attachments sites are determined from digitized muscle insertions, which were derived from its moment arm calculation,[18] and its anatomical descriptions.[19] The model was manually scaled to participant characteristics. The muscle forces for each triceps head were then analyzed using the OpenSim static optimization function.

Using the same-scaled model, each muscle length was also recorded. The starting position was full elbow flexion in order to calculate muscle length. The muscle length for each triceps head was then analyzed using the OpenSim Muscle Analysis function. Muscle lengths were then normalized to the 0° shoulder flexion as the baseline. Changes in the muscle length during different shoulder flexions were then compared for each triceps head.

Muscle activation measurement

Muscle activation of the TB long head, lateral head, and medial head were recorded with Surface Electromyography (Biopac MP150A-CE Data Acquisition System, Biopac System Inc., CA). Ports of the digital channels (HLT100C) were connected to three recording electrodes (TSD150B, 2 cm inter-electrode spacing, Biopac System Inc., CA) and a ground reference electrode (Kendall 100 Series Foam Electrodes, Medtronic, MN). Electrodes were then positioned according to the European recommendations for Surface Electromyography for Non-Invasive Assessment of Muscles (SENIAM)[20] (Fig. 2) on each triceps head. Intra-session reliability of the triceps sEMG recording with similar electrode positioning with a dynamic contraction was shown to have a good relative reliability (ICC = 0.94–0.99) and sufficient absolute reliability (CV (%) = 10.75/10.69).[21]

Categorization of processed data and statistical analysis

Calculated muscle force and normalized muscle activation were categorized based on the corresponding elbow angle intervals (which were 135°–110°, 110°–85°, 85°–60°, 60°–35°, 35°–10° and 10°–0°, with 0° as elbow full extension) and its corresponding shoulder elevation angles (which were 0°, 45°, 90°, 135° and 180°).

Statistical analysis

All statistical analysis was performed with SPSS (SPSS Inc., Chicago, IL). In order to analyze the interaction between each muscle head, a series of repeated measures ANOVA were run. Three-way repeated measures ANOVA was conducted to determine the effects of TB muscle heads, elbow joint angle, and shoulder elevation angle on the muscle force and muscle activity. Subsequently, for each muscle force and muscle activation, a series of two-way repeated ANOVA of the TB muscle heads and the elbow joint angle for each shoulder elevation angle separately. The level of statistical significance for all analyses was set to $P = 0.05$.

Results

Muscle force and activation

We found a difference in the muscle force and muscle activity of each head of TB (Fig. 3). A statistically significant interaction was observed between TB muscle heads and shoulder elevation angle on the muscle force ($F = 155.368$, $p < 0.001$) and muscle activation ($F = 12.593$, $p < 0.001$). This result indicates a different function for each head during different shoulder elevations.

In 0° shoulder elevation, the long head was shown to generate a significantly higher muscle force and muscle activity than the lateral head ($p = 0.000$ and $p = 0.017$, respectively) and also than the medial head ($p = 0.000$ and $p = 0.000$, respectively); however, no significant difference of muscle force and muscle activity were observed between lateral and medial heads ($p = 0.059$ and $p = 0.070$, respectively).

On the other hand, in 90° shoulder elevation, the medial head muscle was shown to increase its generation of muscle force and muscle activity, which were significantly higher than those of the long head ($p = 0.000$ and $p = 0.000$, respectively) and the lateral head ($p = 0.000$ and $p = 0.000$, respectively). No significant differences of muscle force and muscle activity were observed between the long and lateral head ($p = 0.359$ and $p = 0.670$, respectively).

Furthermore, at 180° shoulder elevation, the lateral head muscle increased its generation of muscle force and muscle activity, which