Changes of Elbow Joint Load from Two-handed to One-handed Push-up Exercise

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Abstract

The purpose of this study was to compare the differences of the elbow joint load between two-handed and one-handed pushup exercises. Elbow joint loading was evaluated during two-handed and one-handed pushup exercises using a motion analysis system and a force plate. Results show that in one-handed pushup, large pronation/supination angles were found (p<0.05) and posterior shear force and flexion moment were increased 5 times and 2.5 times, respectively, compared to two-handed pushup. It was noted that greater posterior shear forces and flexion moments of the elbow are encountered not only from loading increasing but also from the muscle coordination for the constraint of joint. Therefore, people with elbow ligament injury are suggested to pay more attention to heavy posterior shear force and flexion moment to avoid injury from two-handed pushup to one-handed pushup.

Keywords: One-handed push-up, Two-handed push-up, Kinematics, Kinetics, Elbow

Introduction

Pushup is a popular exercise. The understanding of kinematics and kinetics of the elbow during pushup helps prevent injury of upper extremity. Reports suggest that patients with medical collateral ligament repair, radial head reconstruction and total elbow arthroplasty should be protected from such exercise immediately after treatment. [1,2]

Either two-handed or one-handed pushup is regarded as not only one of the most popular exercises to strengthen the upper-limb muscles but also the simulated motion for forward falls with outstretched hand [3-5]. Elbow loads were reported during pushup exercise with different hand positions [1] and with various forearm rotations [6]. One-handed pushup is much more difficult than two-handed pushup. Yet the differences of kinematic and kinetic behaviors between two-handed pushup and one-handed pushup, even fall with outstretched hand, were not reported because there are difficulty in measures and analysis in longitudinal study. Muscle forces of the elbow joint were determined by joint constraint, the resultant joint forces and moments due to externally applied load, and line of action of the muscle that crosses the joint. The maneuver of elbow joint from two-handed to one-handed pushup can be changed not only by large loading but by line of action of muscle and joint constraint [4]. Thus, the purpose of this study was to investigate the changes of kinematic and kinetic behaviors of the elbow from two-handed to one-handed push for understanding further the mechanism of falls.

Method

Subjects and Experimental Protocol

Eight physically healthy male subjects volunteered for this investigation. They ranged from 15 to 18 years (17±1.2, mean±SD) of age, from 58 to 85 kg (69.3±9.2) in body weight, and from 164 to 181 cm (171.7±5.2) in body height. None had ever suffered from upper extremity injuries or disorders. All subjects could finish the experimental set of two-handed and one-handed pushups without any uncomfortable feeling.

The ExpertVison motion system (Motion Analysis Corp., Santa Rosa, CA, USA) with six 60 Hz cameras and a 1000 Hz Kistler force-plate (Type 9281B, Kistler Instrument Corp., Winterthur, Switzerland) was used to measure relative joint positions and ground reaction forces.

A set of six reflective markers was placed on selected anatomic landmarks of the subject. The selected anatomic
Figure 1. Marker setup in push-up experiment. The selected anatomic landmarks were intended to simulate the rigid body assumption for upper arm (acromion process, medial and lateral epicondyles of the elbow), forearm (medial and lateral epicondyles of the elbow, ulnar styloid processes), and hand (radial and ulnar styloid processes, third metacarpal bone).

Additional, a triangular frame with three markers was placed on the upper arm in order to minimize potential errors due to skin movement of epicondyles during pushup[6].

Subjects were asked to perform two-handed and one-handed pushups (Figure 1). Before the start of pushup, subjects were asked to keep their bodies in a neutral anatomic position, i.e. arms at their sides and palms facing forward. They were instructed to perform consecutive pushups in the neutral position within approximately 10 seconds so that the dominant hand is kept at the same position during two-handed and one-handed pushups. Five minutes was allowed for rest between trials, in order to avoid muscle fatigue.

Data Reduction

Laboratory-developed kinematics and kinetics software were used to calculate the joint angles, resultant forces and moments of the elbow. A three-segment model, i.e. the hand, forearm and upperarm, was employed in the analysis. Each segment was assumed to be a rigid body. Six CCD cameras were used to record the 3-D position of the markers. Three elbow joint angles, flexion/extension, valgus/varus and axial rotation, were calculated using Euler’s method based on the attached markers [6, 7]. A piezoelectric force plate was used to measure vertical and two shear forces as well as the location of the center of pressure of the palm on the plate and the moment about the axis normal to the force plate during the pushup. Simultaneous measurement of the upper-extremity kinematics was obtained by video recording of the markers. Segment mass and inertia data were estimated by anthropometry [8]. Angular velocity and acceleration were calculated with Euler’s parametric method [9]. The force place loading equals the hand loading, with a reversed vector. The wrist loading is then calculated, using an inverse dynamic procedure with the Newton-Euler equations [9-11].

Data Analysis

The kinematic and kinetic data of the elbow for two-handed and one-handed pushups were analyzed statistically by t-test with p<0.05 as statistical significance [15]. The independent variable was number of hand used for pushup, the two-hand or one-hand, and the dependent variables were the elbow joint angle, resultant force and resultant moment. Captured data at the up, down and peak events of an entire pushup were used for analysis. The "up" event was defined as the moment of initial posture, with the elbow in full extension. The "down" event was defined as the moment when the kinematic or kinetic data were either maximal or minimal.

Results

Joint angle

The joint angles were calculated based on neutral position. The positive joint angles in frontal, sagittal and transversal plane are toward valgus, flexion and supination,
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Figure 2. Mean and standard deviation of (a) varus, (b) flexion, and (c) pronation angles of elbow at up and down event, and peak value of pushup cycle. (* value significantly greater, $p<0.05$, than that of two-handed group.)

Figure 3. Mean and standard deviation of (a) anterio/posterior shear force, (b) medial/lateral shear force, and (c) axial compression force of the elbow at up and down event, and peak value of pushup cycle. (* value significantly greater, $p<0.05$, than that of two-handed group.)
Table 1. Range of Motion of Elbow during One-handed and Two-handed Pushups

<table>
<thead>
<tr>
<th>Range of Motion (degree)</th>
<th>One-handed Mean (SD)</th>
<th>Two-handed Mean (SD)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>varus-valgus</td>
<td>13.5(5.0)</td>
<td>18.1(4.2)</td>
<td>0.07</td>
</tr>
<tr>
<td>Flexion-extension</td>
<td>88.2(26.4)</td>
<td>111.7(11.9)</td>
<td>0.06</td>
</tr>
<tr>
<td>Forearm rotation</td>
<td>45.2(18.0)</td>
<td>27.0(15.1)</td>
<td>0.04*</td>
</tr>
</tbody>
</table>

* : p<0.05

events in one-handed pushup were significantly smaller from those in two-handed pushup (p<0.05, Figure 2). However, the range of motion in axial rotation (pronation-supination) of the forearm was much greater in one-handed pushup than in two-handed pushup (Table 1).

### Elbow Joint Force

The sign conventions used in the elbow joint resultant force graphs are that the loads are calculated in terms of the upper arm segment acting upon the forearm segment. At down and peak events, the shear force of the elbow in sagittal plane was posterior and significantly greater in one-hand pushup compared to two-handed pushup (p<0.05, Figure 3). In coronal plane, the peak medial-lateral shear force of the elbow is medially directed and significantly greater in one-handed group compared to two-handed group (p<0.05). The largest joint force component in the elbow was compressive axial force comparing with anterior-posterior and medial-lateral shear forces. The axial compressive force of the elbow in the one-handed group was significantly greater than that in the two-handed group at up, down and peak events (p<0.01).

### Elbow Joint Moment

The elbow joint resultant moments are expressed in terms of external moments. Shown in Figure 4 is the external moment acting at the elbow joint during push-up exercise. In frontal plane, the peak varus moment of elbow in one-handed group was significantly greater than that in two-handed group (p<0.05). In addition, the flexion and pronation moments of the elbow in one-handed group were significantly greater than those in two-handed group at up, down and peak events (p<0.05).

### Discussion

Push-up is a very popular exercise for training the upper-limb muscles, while one-handed push-up is the utmost challenging part of it. With various hand positions, the mechanism of push-up was reported related with the pattern of falls with outstretched hand [1, 3, 4]. Donkers’ study noted that elbow joint loading was affected significantly with hands positions during two-handed pushup [1]. The flexion moment of elbow was increased with hands apart and decreased with hands together. In Lou’s study, elbow joint loading was significantly different with various forearm rotations [6]. The valgus shear force of elbow was increased with internal handed position. Paul’s study found that valgus shear force of elbow was increased with external handed position during one-handed pushup [16]. In this study, the protocol was performed at two-handed and one-handed pushups for...
purposes of detailed investigation of the changes of biomechanical behaviors of the elbow from two-handed pushup to one-handed pushup at up, down and peak events during pushup exercise.

Muscle force can be determined by joint constraint, the resultant joint forces and moments, and line of action of the muscle. Thus, the kinetics of elbow was affected significantly with handed position and forearm rotations. In this study, the range of motion in pronation/supination is significantly different between two groups. In contrast, the varus and flexion angles of the elbow didn’t show significant difference between one-handed and two-handed pushups. The posterior shear forces and flexion moment of the elbow during one-handed pushup exercise were 5 and 2.5 times, respectively, of those in two-handed pushup. The medial shear and compression forces of the elbow in one-handed pushup were about 2 times of those in two-handed pushup. The increased forearm rotation in one-handed pushup was to recruit more muscle force to compensate large external force due to one hand loading. This can be confirmed by more than 2 times of posterior shear force and flexion moment produced in one-handed pushup compared to two-handed pushup. This strategy would be regarded for maintaining the stability and resisting heavy loadings during one-handed pushup exercise.

The medical collateral ligament, the important constraint for stabilizing the elbow, was prone to be injured under large mediolateral shear force. In this study, the medial shear force in one-handed pushup was almost 2 times of that in two-handed pushup. This result can be proved from the comparison of studies of Lou et al. [6] and Chou et al. [16]. It should be paid more attention. Compared with prosthesis losing of one-degree of freedom and semi-constrained prosthetic design [17], the mechanism of elbow, various forearm rotation for elbow loading, can be possibly used for the prosthetic design to avoid prosthesis loosing under loading of dairy activity of life.

Conclusion

Compared to two-handed pushup exercise, large pronation/supination angles were produced for recruiting more muscle forces to maintain stability and resist large external force during one-handed pushup. In addition, the posterior shear force and flexion moment were increased 5 times and 2.5 times, respectively. People with elbow ligament injury should pay more attention to heavy posterior shear force to avoid injury during one-handed pushup.

Acknowledgments

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References