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The Effects of Elbow Joint Angle Change on the Elbow Flexor Muscle Activation in Pulley with Weight Exercise

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Abstract. [Purpose] This research investigated the effect of angular variation of flexion of the elbow joint on the muscle activation of elbow flexor muscles. [Subjects] The research subjects were 24 male college students with a dominant right hand who had no surgical or neurological disorders and gave their prior written consent to participation with full knowledge of the method and purpose of this study. [Methods] The subjects' shoulder joints stayed in the resting position, and the elbow joint was positioned at angles of 55°, 70°, and 90°. The angle between the pulley with weights and forearm stayed at 90°. Surface electromyography was used to measure muscle activities. Three measurements were made at each elbow angle, and every time the angle changed, two minutes rest was given. [Result] The muscle activities of the elbow flexors showed significant changes with change in the elbow joint angle, except for the biceps brachii activities between the angles of 55° and 70° of elbow flexion. The muscle activities of the biceps brachii and brachioradialis showed angle-related changes in the order of 55°, which showed the biggest value, followed by 70° and 90°. [Conclusion] In order to improve muscle strength of the elbow flexor using a pulley system, it seems more effective to have a 90° angle between the pulley with weights and the forearm when the muscle is stretched to a length 20% greater than its resting position.
Key words: Pulley with weight exercise, Joint angle, Muscle activation

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INTRODUCTION

A pulley system is a useful tool for facilitating articular rehabilitation and muscle strengthening. Especially, the pulley with weight is relatively easy to standardize, and readily available in places like hospitals and fitness centers for improving muscle strength and muscle endurance[1)]. The pulley with weight is an exercise in which weights are lifted using a pulley system. This fitness equipment can be used to create a variety of joint angles and muscle lengths. Kapandji et al.[2)] noted that the angle of the joint was related to muscle length, so muscle strength would vary according to the angle of the joint. Also, Norkin[3)] reported that the moment of force was affected by the angle of the joint and muscle length, and Kim et al.[4)] reported that angular variation of the joint changes muscle activation. Thus, to heighten the effect of pulley exercise with change in the joint angle and muscle length, the weights of the pulley system or the subject's joint angle need to be changed. Nevertheless, there is little guidance and research regarding the joint angle and the method for exercise using the pulley system.

From the aspect of biomechanics, change in the joint angle results from periarticular muscle contraction[5)]. The change in the joint angle leads to change in the lever arm length and muscle length, and this accompanies variation in muscle contraction[6)]. Therefore, there should be a joint angle which has an optimal mechanical advantage in each joint[5)], and the optimal muscle length would be at the angle which exercises maximal strength[3)]. Consequently, the muscular strength would be determined by the length-tension relationship and the mechanical characteristics of the lever. In order to perform an exercise for muscle strength improvement, it is important to know the relationship between the muscle strength and the joint angle of the muscle[7)]. It has been reported that when the muscle length increases, the muscle activation begins to decrease[8–10)]. It has also been reported that the muscle length is unrelated to muscle activation[11)]. However, recently, Deusen[12)] showed that the muscle length affects muscle contraction, and reported that there was a relationship between the muscle length and muscle activation. Thus, it can be assumed that there must be a

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muscle length that generates optimal strength, and it seems meaningful to study the joint angle and muscle activation because of the close connection between muscle length and joint angle. Particularly, considering this aspect, an exercise program needs to be developed for the pulley exercise with changes in joint angle and muscle length, because knowing the joint angle that creates maximal strength increases the effect of the pulley exercise. Therefore, this study was conducted in order to find out the joint angle which creates maximal muscle activation using a pulley system, based on the premise that the joint angle is related to muscle activation. Also, this research offers basic data for the development of an effective exercise program for muscle strength improvement.

SUBJECTS AND METHODS

The research subjects were 24 healthy male students attending S university in Busan, Republic of Korea, who gave their prior written consent to participation. They were right-handed, had no congenital deformity in upper extremity which would have affected the results of this study, no surgical or neurological disorders, and no pain in the neck, back, or shoulder. Their average age was 30.38 years, their average height was 175.8 cm, and their average weight was 75.09 kg. Surface electromyography (Keypoint, Medtronic, USA) was used to measure muscle activations of the brachioradialis and biceps brachii at different elbow joint angles with the shoulder joint in the resting position. The electrodes were 1.5–2.5 centimeter disposable unipolar surface electrodes. The angle between the shoulder joint and elbow joint was measured using a goniometer (Anymedi, Korea). To trigger the contraction of elbow flexor, a special, customized pulley system with an electric motor was used. The pulley system could control the load amount in one-hundred-gram units according to the muscle strength, and could provide the merit of maintaining the load regardless of the length of the rope in a pulley system. To show the effect of angular variation of the elbow joint on the muscle activation of elbow flexor muscles, the non-dominant hand, the left hand, was used. The subjects were made to stand with their feet shoulder width apart, and their shoulder joints and elbow joints were placed in a resting position. For the resting position, the shoulder joint was abducted at 55°, and horizontally abducted at 30°; and the elbow joint was flexed at 70°, and supinated at 10°[13]. During the pulley exercise, the resting position of the shoulder joint was maintained, while the angle of the elbow joint was positioned at 3 different angles. Sohn et al.[14] reported the maximum tension was likely to be developed at 1.2 times the length of the muscle in the resting position. Thus, the flexion angle of the elbow joint was positioned at 55° in the first step; at 70°, the same as the resting position of the elbow joint, in the second step; and at 90°, the angle usually used during exercise, in the third step. A 90° angle was made between the pulley system and the forearm. When the muscle contracts, the change in muscle strength is proportionate to the change in the electromyogram value, because the action potential occurs in the muscle[4]. Consequently, to detect the change in the muscle strength due to the angular variation at the elbow joint in the resting position of the shoulder joint, isometric contraction was induced, and then the muscle activation was measured using surface electromyography. Isometric contraction was performed for 5 seconds, and the electromyogram of the 4 seconds, excluding the first second, was recorded. Three measurement trials at each elbow angle were made, and two minutes rest was given before changing the angle of the elbow joint, based on the preceding studies, to prevent the muscle fatigue[15]. The flexion of the elbow joint is induced by the brachialis, biceps brachii, brachioradialis, pronator teres[16], but we only recorded the electromyograms of the biceps brachii and brachioradialis due to the ease of their measurability. The electrodes were attached 2 centimeters apart at the thickest part of the muscle belly after muscle contraction[17]. Before the electrodes were attached, hair on the attachment site was removed by shaving to reduce the skin resistance, and then the site was cleaned with an alcohol swab for exfoliation. The ground electrode was attached to the non-dominant left triceps brachii. To determine the significance of the changes in muscle strength due to the angular variation of the elbow, repeated measures ANOVA was conducted. To find the joint angle which showed differences in the muscle activation, Wilcoxon's Signed Rank test, a nonparametric method, was performed, because the Shapiro-Wilk's test showed the data were not normally distributed. For the analysis, we used SPSS for Windows (Ver. 20.0) statistical software, and a significance level of α=0.05.

RESULTS

The muscle activations of the biceps brachii and brachioradialis showed statistically significant changes with changes of the elbow joint. The muscle activities of the biceps brachii were 366.5 mV at 55°, 295.3 mV at 70°, and 159.9 mV at 90° ($p<0.05$). The muscle activities of the brachioradialis were 1678.1 mV at 55°, 1043.3 mV at 70°, and 362.4 mV at 90° ($p<0.05$). The muscle activation of the biceps brachii was not significantly different between the elbow angles of 55° and 70°; however, between 55° and 90°, the muscle activation was significantly higher at 55° ($p<0.05$), and between 70° and 90°, the muscle activation was significantly higher at 70° ($p<0.05$). For the brachioradialis, between elbow angles of 55° and 70°, the muscle activation was significantly higher at 55° ($p<0.05$), between 55° and 90°, the muscle activation was significantly higher at 55° ($p<0.05$), and between 70° and 90°, the muscle activation was significantly higher at 70° ($p<0.05$) (Table 1).

DISCUSSION

The bones of the human body are connected through joints[18], and the human body can adopt various postures due to angular movement of the joints[19]. The movements of the joints are developed through muscle contraction, which is closely connected with muscle length[20]. In other words, changes in muscle length lead to changes in joint angles, affecting the muscle's strength[21]. The change in the muscle strength depending on the angular variation of the

Table 1. Muscle activities at different angles of elbow flexion (unit: mV)

Muscle	Elbow Angle		
	55°	70°	90°
Biceps brachii*	366.5 ± 339.5[a]	295.3 ± 295.2[b]	159.9 ± 95.0
Brachioradialis*	1678.1 ± 1805.6[c, d]	1043.3 ± 1164.3[e]	362.4 ± 347.3

Mean ± SD. *: Repeated measures ANOVA test ($p<0.05$)
a: 55°>90° ($p<0.05$), b: 70°>90° ($p<0.05$), c: 55°>70° ($p<0.05$), d: 55°>90° ($p<0.05$), e: 70°>90° ($p<0.05$) by Wilcoxon's Signed Rank test

elbow joint can be explained through the lever principle and the length-tension curve of the muscle. In explaining the movement of the human body using the lever principle, the fulcrum is the joint, the force generating the effect is the muscle, and the weight or resistance is the human body[22]. In this respect, change in the joint angle accompanies the change in the length of the lever arm and muscle, leading to change in the muscle activation and contraction[4, 6]. Also, the biggest tension is developed at a specific range of musle length in the length-tension curve, which is why the change in the muscle strength induced by angular variation of the elbow joint can affect the muscle activation[23]. In this context, Eloranta and Komi[11] and Bobbert and Harlaar[24] confirmed that isokinetic contraction of extensor muscles and electromyogram values of maximum voluntary isometric contraction were the biggest at the middle range of angles, and that is why correlation exists between the joint angles and muscle activation. Kim et al.[25] argued that during specific movements, the muscle length and joint position changes constantly, causing change in the moment of force. Consequently, they said that when a muscle contracts, the muscle strength will differ depending on the angular variation. Lee et al.[26] also reported that during movement, if proper muscle length and joint position were set, a subject would display the maximum power in the easiest way, and perform exercise properly. Thus, if the exercise were done with a pulley system, consideration of the joint angles would be an important factor for the maximum effect of the exercise. Nevertheless, there are few studies which have scientifically investigated the optimal joint angle, which can improve the effect of the exercise when using a pulley system. Thus, the object of this study was to provide basic data concerning the proper joint angle during pulley exercise.

Borstad[27] researched the relationship between the changes in muscle length relative to the resting position and damage to the shoulder joint. He argued that change of the resting position occurred when the resting length of the muscle involved in the related movement became shorter. Therefore, when joint angles were selected for this study, three elbow angles were chosen considering to the resting position of the elbow joint and the length tension relationship of the muscle. While the shoulder joint was placed on the resting position, the elbow joint was flexed at an angle of 70°, which is its resting position, in the first step. In the next step, it was flexed at an angle of 55°, which gives a length 20% greater than the resting position. Finally, the elbow was flexed at an angle of 90°, which gives a length 30% less than its resting position. Since the change in muscle activation depends on the angular variation of the elbow joint, the biceps brachii and brachioradialis were measured. Only the muscle activation of the biceps brachii showed no significant difference between the elbow angles of 55° and 70°. The other muscle activities of the biceps brachii and brachioradialis showed angle-related changes in the order of 55°, which showed the biggest value, followed by 70° and 90° ($p<0.05$). Therefore, the results suggest it would be more effective to make an angle of 90° between the pulley with weights and the forearm when the muscle is stretched to a length 20% greater than its resting position. This result and those of other studies' agree with the study of Sohn[14], who reported the smaller the angle of the elbow joint was, the higher the muscle activation was. Also, Nam and Kim[28] varied the angle of the flexion of the elbow joint from 110° to 70° at 5° intervals, and investigated the muscle strength. They reported that the smaller the angle of flexion of the elbow joint was, the higher the muscle activation was, and that the rate of increase in the muscle strength was the highest at an angle of 70°. This is in consistent with the results of the present study, that the muscle strengths of the biceps brachii and brachioradialis were higher at an angle of 90° than at 70°. Although, most studies have not provided a scientific basis that is applicable to all joints, the results of the present study can be generalized to all joints because the angles at which the muscle length was stretched by 20% compared to the resting position of each joint were used. The results of this study can be explained through the results of the study by Cooke and Fay[29]. They showed that the active force at the resting length was the greatest, but if the muscle length were stretched by 20 to 30% of its resting length, the bigger the passive force became, and the bigger the total force was. That's why the results of the present study show that the muscle activation became greater, because active force was added to the passive force at the angle at which the muscle length was stretched by more than 20% of its length.

Consequently, in order to improve the muscle strength of the elbow flexor using a pulley system, it would be more effective to set an angle of 90° between the pulley with weights and the forearm, and use an angle at which the muscle is stretched to a length 20% greater than its resting position. However, more research is needed to confirm this result through a comparative study of muscle activations at angles at which the muscle length is stretched by more than 20% from its resting length and using joints other than the elbow, which was studied in the present study.

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