Original article

Function of the anconeus muscle in the elbow joint

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Abstract

Main functions of anconeus muscles are considered to be elbow joint extension. It is assumed that the anconeus muscle is a muscle with a braking function for varus movement for the elbow joint from the anatomical features such as the direction of muscles and smallness of the muscle volume. However, there have been no research reports that indicate characteristics of anconeus muscles in vivo. Therefore, in this study, for the purpose of elucidating a braking function for varus movement of anconeus muscles in detail, the authors derived EMGs in extending and valgus movement of an elbow joint as well as measured elbow joint extension torque and observed dynamics of humerus and ulna by ultrasound imaging in the case that tetanic contraction was induced by electrically stimulating anconeus muscles. Eight healthy adults were employed as subjects, and EMGs were derived with wire electrode from anconeus muscles in addition to long head of triceps brachii muscles for comparison. The measurement positions were 4 flexed positions of 10°, 30°, 60° and 90° in the elbow joint. As a result, the anconeus muscles' activity increased in the flexion range for extension movement and in the extension range for valgus movement. Activity of the long head of triceps brachii muscles in the case of valgus movement was an extremely low value. Extension torque caused by electrical stimulation to anconeus muscle did not occur in the extension range, and dynamics that ulna biased into the valgus direction was observed in two subjects. From these results, the anconeus muscle was judged as a muscle with the valgus function of the elbow, in other words, a braking function for varus in the elbow extension region.

Introduction

The anconeus muscle is a small muscle having an origin on lateral epicondyle of humerus and insertion on olecranon, and it is thought that its main function is elbow joint extension movement [1-4]. However, there is strong agonist, such as triceps brachii muscle for an elbow joint extension movement. Moreover, muscle volume of the anconeus muscle is around 1/10 of that of the triceps brachii muscle, and moment arm of the extension is also extremely small [4,5]. It is inferred from these characteristics that the anconeus muscle has func-

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tions that are important other than the elbow extension movement. As for functions except elbow extension movement of anconeus muscle, it has been revealed by anatomical studies that anconeus muscle has runs similar to those of lateral collateral ligaments, which have a stabilizing function to break the varus movement of the elbow joint, and adhere to the lateral joint capsule of humeroulnar joints [6,7], and therefore it is supposed that anconeus muscle has a dynamic stabilizing function to brake the varus movement. Moreover, a study of electromyography (EMG) reported that anconal activity was seen during valgus movement [1] and therefore the idea that anconeus muscle has a dynamic stabilizing function of the elbow joint is coming to be supported more [7-11]. However, there have been no research reports that indicate characteristics of the anconeus muscle in vivo. Therefore, in this study, the authors aimed at clarifying a braking function for varus movement of anconeus muscle by EMG analyzing muscle activity of it during extension and valgus movement of the elbow joint. Moreover, in order to examine how the anconal activity obtained by the EMG study is involved with the elbow joint, the observation with ultrasound imaging of dynamics of humerus and ulna in the case that anconeus muscle was contracted by electrical stimulation was added to the study purpose. In previous studies, there is a report that the anconeus muscle activity varies depending on the elbow joint and forearm position. Therefore, this study also examined the effect of the joint position [1,2].

Materials and Methods

1. Subject

Eight healthy adults with no medical history of neuromuscular diseases and orthopedic diseases were employed for the study. The subjects consisted of 8 males with average age of 36 ± 8.4 years old. All of them were right-hander. Further, this study was conducted approval by the Ethics Committee of Niigata University of Health and Welfare (Approval No:17341-120817), and the subjects were explained about the purpose and method in document and consent was obtained.

2. Analysis of EMG of anconeus muscle and triceps brachii muscle

1) Movement task

The movement tasks were isometric elbow extension and valgus movement of the right elbow by the maximum effort. For the elbow valgus movement, the subjects were instructed not to cause elbow extension movement. An elbow joint torque measuring instrument was used for these tasks and Digital Force Gauge (RZ-100, Aikoh Engineering, Japan) was used for both extension and valgus movement (Figure 1). The valgus movement of the elbow joint is not a physiological movement. For that reason the valgus movement also takes into account the torque value of the horizontal abduction movement of the shoulder joint. The position for the tasks was sitting posture on a chair, with the shoulder flexed by 90° and abducted by 0°. Moreover, 4 positions of the elbow flexed by 10°, 30°, 60° and 90° for both tasks and 2 positions of the maximum supination and pronation for forearm at each elbow position were set. The isometric contraction was performed for 3 seconds for each task, which was performed twice at one position. The subjects were allowed to take a break for 1 minute to avoid fatigue of muscles and the elbow and forearm positions were randomized.

2) Insertion of wire electrode

The target parts for the study were the right anconeus muscle and long head of the triceps brachii muscle. The long head of triceps brachii muscle is a main muscle of the elbow extension, and electrodes were inserted in it for the comparing its activity with that of the anconeus muscle. Wire electrodes for deriving EMGs and electrical stimulation were inserted in the distal part of the anconeus muscle. Furthermore, for electrical stimulation, an additional electrode was inserted in the proximal part of the anconeus muscle to obtain

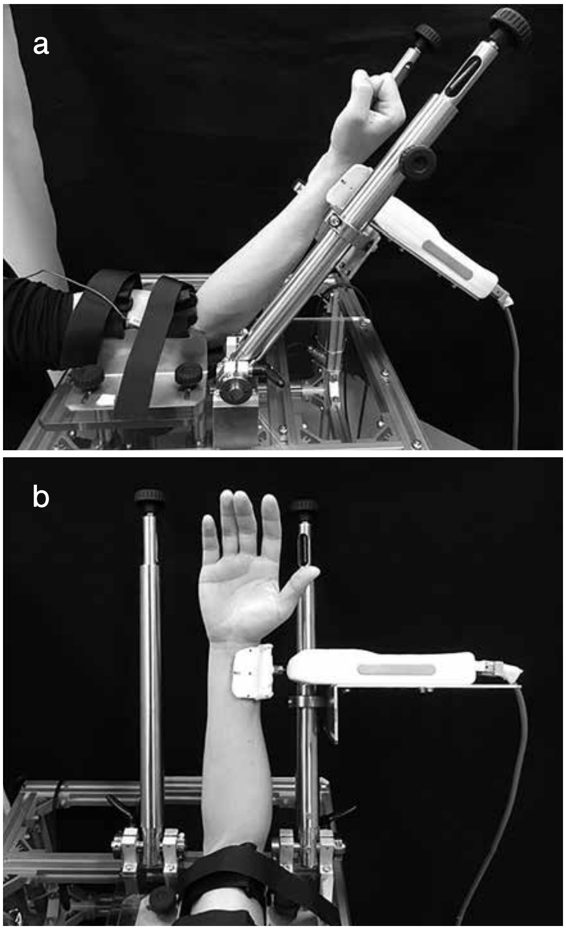

Figure 1. Measurement of EMGs of anconeus muscle and triceps brachii muscle.
The movement tasks were isometric elbow extension (a) and valgus (b) movement, which were measured with an elbow torque measuring instrument.

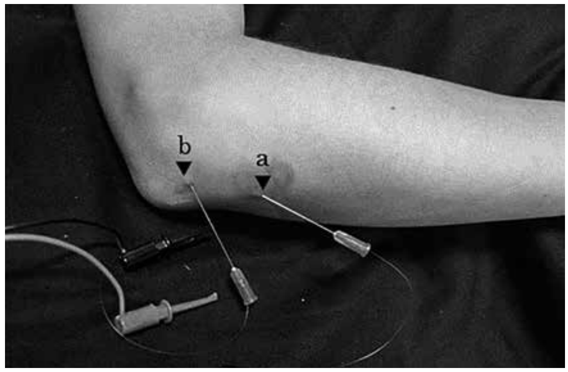

Figure 2. Insertion of wire electrodes to anconeus muscle.
The wire electrodes for deriving EMGs and electrical stimulation (a) were inserted in the distal part of the anconeus muscle. Furthermore, for electrical stimulation, an additional electrodes (b) were inserted in the proximal part of the anconeus muscle to obtain tetanus.

tetanus of the anconeus muscle (Figure 2). For the long head of triceps brachii muscle, the electrodes were inserted in the proximal 1/3 part of the muscle belly from the inside on the posterior surface of upper arm. The insertion site of the wire electrode in both muscles was performed with reference to a previous study [12]. The wire electrodes were bipolar pasting wire electrodes made of stainless wire of 0.05 mm in diameter coated with rigid urethane (TN204-123, Unique Medical, Japan), and fixed with non-isolated part of 2 mm and inter-electrode distance of 5 mm. Furthermore, the electrodes' tips were bent into a hook by approximately 15 mm so that electrodes followed with contraction of the muscles. The 25-gauge needles were used as a guide for insertion of the electrodes and only the guide needles were removed after insertion of the electrodes. For confirmation of electrode sites, electrical stimulation was given with the inserted bipolar wire electrodes and it was confirmed that the anconeus muscle and the long head of triceps brachii muscle contracted independently before placing the electrodes. It was confirmed after electrodes placement that muscular activity was not derived during muscle contraction of the wrist and fingers. Moreover, the same monopolar wire electrode was inserted in the olecranon section as a ground electrode.

3) EMG analysis

Each muscular EMG signal derived with the wire electrodes was amplified hundredfold with an EMG amplifier (DL -140, 4 Assist, Japan), A/D-converted with sampling rate of 2 kHz together with the signal of the torque via an analog output box (DL -270, 4 Assist, Japan), and taken in a personal computer. A data acquisition / analysis system (Power Lab 8/35, AD Instrument, Australia) was used for the uptake of these data. The recorded EMG signals were processed by a band-pass filter of 10-1000 Hz. While the tasks were performed twice, the EMG data with greater torque were adopted. The time interval of EMG signals to be analyzed was 500 msec after the time point at which torque reached its maximum after starting tasks, and integrated electromyogram (IEMG) was calculated after full-wave rectification. The IEMG obtained by each task was normalized with the maximum IEMG value of each subject as a standard (Normalized IEMG; NIEMG). Subsequently, average values and standard deviation of NIEMG among subjects were calculated for every measurement position.

3. Analysis of elbow joint extension torque during electrical stimulation of anconeus muscle

The positions for measurement were sitting posture on a chair, and the right upper arm and forearm were fixed on a fixing apparatus installed on a desk with the shoulder flexed by 90° and abducted by 0°. The fixing apparatus was equipped with a bearing system in the flexion axis part of the elbow joint, providing a function that removes the gravity of forearms to enable smooth operation. For electrical stimulation, the proximal and distal parts of the anconeus muscle were stimulated simultaneously, and extension force of the elbow at the time of tetanus was measured. The electrical stimulation strength was 1.2 times as great as that the strength by which the maximum extension force was obtained at the elbow flexed by 90°, with the stimulation pulse width of 200 μsec and the stimulation frequency of 20 Hz (electrostimulator: SEN-3401 Nihon Kohden, Japan). Digital Force Gauge (RZ -100, Aikoh engineering, Japan) was used for measurement of extension force of the elbow. The sensor part of the digital force gauge was set on the proximal part approximately 1cm from the styloid process of ulna, vertically against the long axis of the forearm (Figure 3). The positions for measurement were 4 positions of the elbow flexion by 10°, 30°, 60° and 90° same as the EMG measurement, and 2 positions of the maximum supination and pronation for forearm at each elbow position were set. Each task was performed twice at one position. The subjects were allowed to take a break for 1 minute to avoid fatigue of muscles and the elbow and forearm positions were randomized.

Elbow extension torque was obtained by multiplying the obtained force values by the distance from the lateral epicondyle of humerus to the sensor part, and average values of the two measurements at each position were calculated. Subsequently, average values and standard deviation among the subjects were calculated for each position.

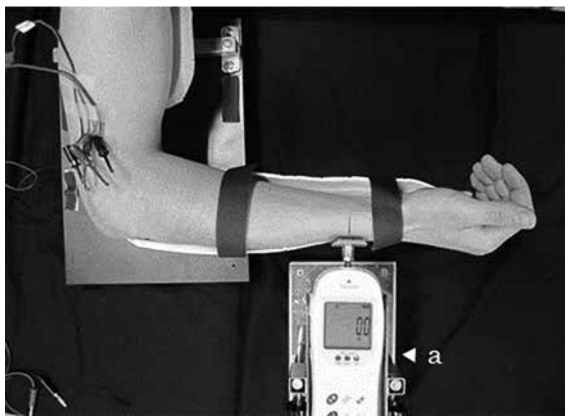

Figure 3. Measurement of elbow extension torque by electrical stimulation to anconeus muscle.
Digital Force Gauge (a) was used for measurement of extension force of the elbow. The sensor part of the digital force gauge was set on the proximal part approximately 1cm from the styloid process of ulna, vertically against the long axis of the forearm.

4. Observation by ultrasound imaging under electrical stimulation for anconeus muscle

Dynamics of humerus and ulna with the anconeus muscle electrically stimulated was observed with ultrasound imaging of an ultrasonic diagnostic equipment (Viamo, Canon Medical Systems, Japan). The observed positions were the shoulder flexed by 90° and abducted by 0°, the elbow flexed by 10° and the forearm on supination position. Strength and conditions of the electrical stimulation were same as the elbow extension torque measurement by electrical stimulation to anconeus muscle. The probe was placed on the short axis direction on the distal part approximately 2 cm from the region between the olecranon and the lateral epicondyle of humerus and was set so that physical relationship between the lateral epicondyle of humerus and the ulna olecranon was depicted on the short axis image. As for the measurement, indices were made on the humerus and ulna on ultrasound imaging, and distance between the indices were observed before and during the stimulation was given.

5. Statistic processing

For EMG data, triceps brachii muscle and anconal NIEMG were compared by three-way repeated measures ANOVA with the elbow joint position and forearm position and Muscle as within subject factors. Bonferroni test was employed as a post hoc test for EMG. Elbow joint extension torque, two-way repeated measures ANOVA with the elbow joint position and forearm position as factors was used for comparison among positions. Tukey's HSD test was employed as a post hoc test for elbow joint extension torque. Both a post hoc test for the significance level was set at $p = 0.05$. Further, an SPSS analysis software (IBM SPSS statistics Ver.18, SPSS Japan Inc, an IBM company, Japan) was used for the above statistical processing.

Results

1. EMG analysis of anconeus muscle and triceps brachii muscle

Figures 4 or 5 showed average value ± standard deviation of NIEMG of the anconeus muscle and long head of triceps brachii muscle in the isometric elbow extension and valgus movement.

In the isometric elbow extension, the main effects were observed muscle and elbow joint positions ($F_{1,7} = 8.42$, $p = 0.02$, $F_{3,21} = 5.72$, $p < 0.01$). Two-way interaction was significant in muscle and elbow positions ($F_{3,21} = 4.87$, $p = 0.01$). As Two-way interaction was observed, simple main effect was analyzed. As a result, the simple main effect between the elbow joint positions in the anconeus muscle was significant ($F_{3,21} = 10.78$, $p < 0.01$). For the isometric elbow extension, the anconeus muscle presented activity of 85% of the maximum activity on the elbow flexed by 90° while on the other hand it was as low as 48-57% on the elbow flexed by 10°, showing the tendency of decreasing with a decrease in the elbow flexion angle ($p < 0.01$). The long head of triceps brachii muscle presented 72-84% of the maximum activity at either positions, and no difference caused by the elbow positions.

In the isometric elbow valgus movement, the main effects were observed muscle and elbow joint positions ($F_{1,7} = 10.77$, $p = 0.01$, $F_{3,21} = 4.59$, $p < 0.01$). Two-way interaction was significant in muscle and elbow positions ($F_{3,21} = 7.76$, $p = 0.01$). As Two-way interaction was observed, simple main effect was analyzed. As a result, the simple main effect between the elbow joint positions in the anconeus muscle was significant ($F_{3,21} = 7.35$, $p < 0.01$). For the isometric elbow valgus movement, the anconeus muscle showed tendency of increasing with a decrease in the elbow flexion angle in contrast to the elbow extension movement ($p < 0.01$). In the elbow flexed by 90°, the activity was as low as 20-32%, while on the other hand it was 52-59% in the elbow flexed by 10°, demonstrating that its activity was higher

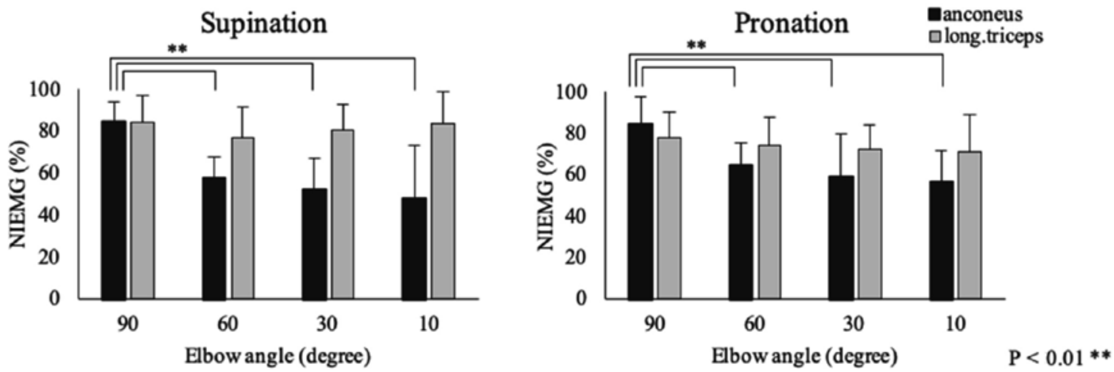

Figure 4. NIEMG of anconeus muscle and long head of triceps brachii muscle in elbow extension movement.
Activity of the anconeus muscle in elbow extension movement presented a tendency that it significantly decreases with a decrease in the elbow flexion angle (p < 0.01). The long head of triceps brachii muscle indicated high activity in either positions. NIEMG: Normalized IEMG.

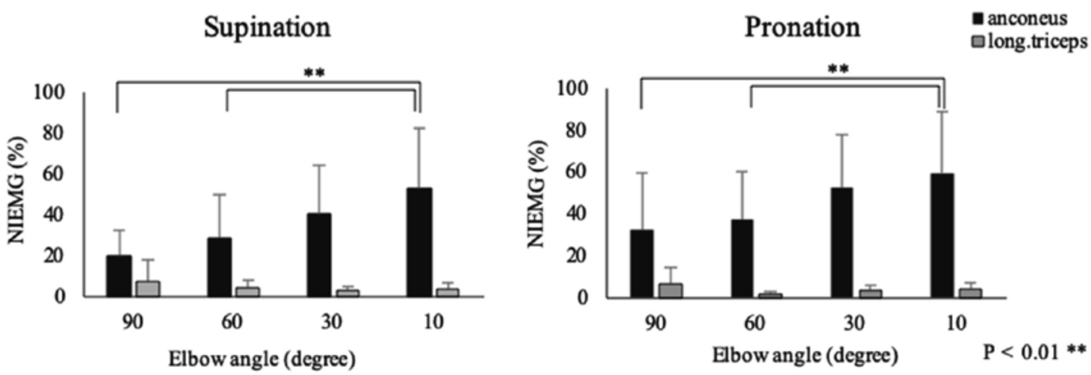

Figure 5. NIEMG of anconeus muscle and long head of triceps brachii muscle in elbow valgus movement.
Activity of the anconeus muscle in elbow valgus movement presented a tendency that it significantly increases with a decrease in the elbow flexion angle (p < 0.01). Activity of the long head of triceps brachii muscle was as low as less than 10% in either positions. NIEMG: Normalized IEMG.

in the extension range. For the long head of triceps brachii muscle, the activity was as low as less than 10% in either positions and no difference by elbow positions was seen.

2. Elbow extension torque with electrically stimulated anconeus muscle

Figure 6 showed average values of the elbow extension torque under the condition that the anconeus muscle was electrically stimulated. The

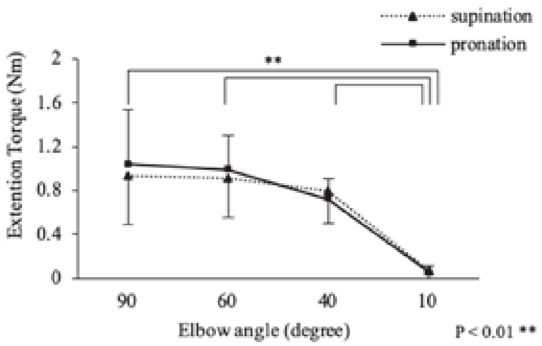

Figure 6. Elbow extension torque by electrical stimulation to anconeus muscle.
The elbow extension torque obtained by electrical stimulation decreased as the elbow reached extension range ($p < 0.01$) and it was not almost seen at the elbow flexion of 10°.

results of repeated measures two-way ANOVA, the Main effects were observed the elbow joint ($F3, 21 = 14.98$, $p < 0.01$). No interaction was observed. Elbow extension torque by the anconeus muscle electrically stimulated significantly decreased with a decrease in elbow flexion angle ($p < 0.01$), and extension torque was not almost presented at the flexion of 10° in all subjects. Moreover, even in the case that electrical stimulation was given without a tensiometer installed, the elbow extension stayed at around -45°, and further extension was not observed (Figure 7a and b). On the other hand, in the case of electrical stimulation at the elbow flexion of 10°, valgus movement occurred in two subjects, not elbow extension (Figures 7c and d).

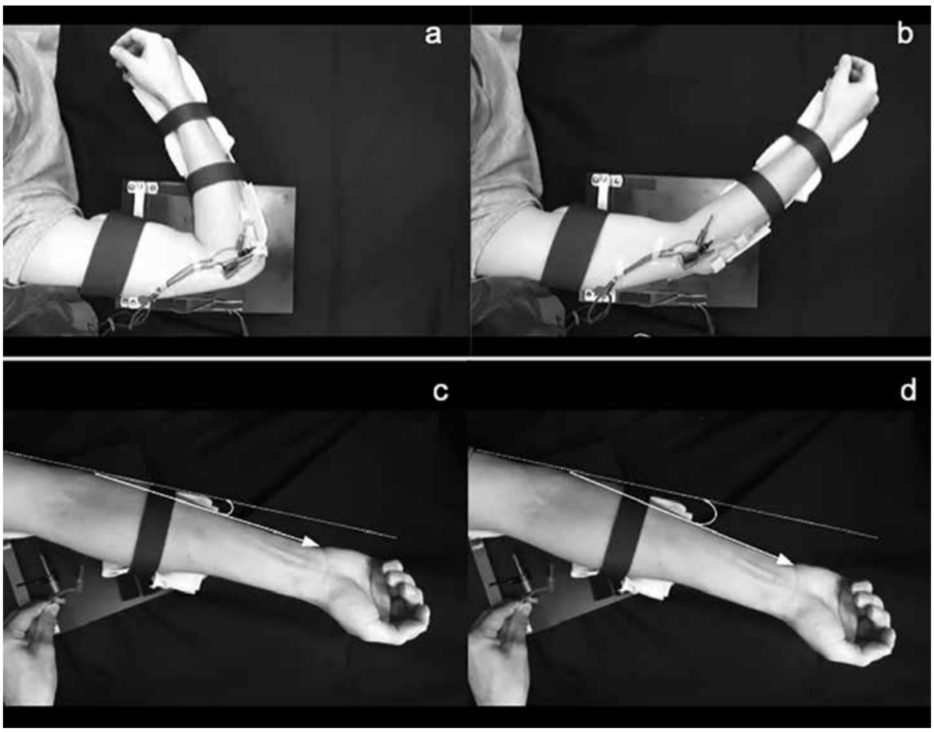

Figure 7. Elbow movement by electrical stimulation to anconeus muscle.
Extension movement of the elbow by electrical stimulation to anconeus muscle was confirmed though the elbow extension stayed at around -45° (a: before electrical stimulation b: during electrical stimulation). Valgus movement was seen in two subjects (c: before electrical stimulation, d: during electrical stimulation).

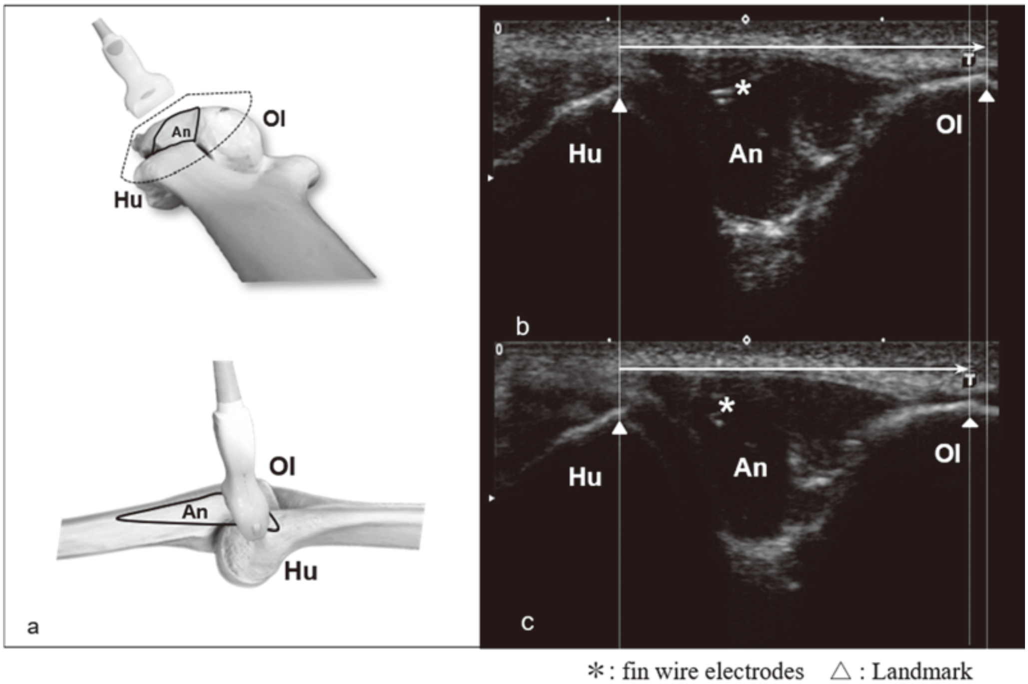

Figure 8. Observation of ultrasound imaging in electrical stimulation to anconeus muscle. The probe was placed on the short axis direction on the distal part so that physical relationship between the lateral epicondyle of humerus (Hu) and the ulna olecranon (Ol) was depicted on the short axis (a). The distance between Hu and Ol shortened by electrical stimulation to anconeus muscle (An) was confirmed (b: before electrical stimulation, c: during electrical stimulation).

3. Observation of ulna in ultrasound imaging with electrically stimulated anconeus muscle

In two subjects whom elbow valgus movement was seen in the case that electrical stimulation was given, the ulna shifted into a valgus direction with contraction of the anconeus muscle (Figure 8). In other subjects, contraction of the anconeus muscle was observed while on the other hand the shift of the ulna was not seen.

Discussion

The anconeus muscle may have a valgus function, in other words, a braking function for varus movement, other than the elbow extension function. In this study, activity characteristics of the anconeus muscle during elbow extension and valgus movement was analyzed by EMG. Moreover, measurement of extension torque in the case that anconeus muscles were contracted by electrical stimulation was performed and dynamics of humerus and ulna was observed in ultrasound imaging.

Activity of long head of triceps brachii muscle in the active elbow extension was as high as around 70-80% of the maximum activity in either elbow positions. In contrast, activity of the anconeus muscle showed a tendency to decrease as the elbow joint moves toward the extension position regardless of the forearm positions, and the activity was around a half of the maximum activity at the elbow flexion of 10°. From the anatomical features of the anconeus muscle, based on the idea that length of the anconeus muscle increases by the elbow reaching flexion position, which raises static tension of muscle, an increase in activity at the flexion position raises the extension force. Therefore the anconeus muscle is an effective elbow extension muscle in the flexion range of the elbow, the authors presume. It is well known that muscular activity is influenced by difference in joint positions and length of the muscle [13-17] and variation of moment arms [18,19]. Since moment arm of the anconeus muscle regarding the elbow extension is not fluctuated with elbow joint positions [5,7], activity of an anconeus muscle may be influenced by muscle length. Moreover, considering the state that muscle length is short in the elbow extension position, and extension force of the elbow is not obtained effectively, we suppose that the activity of the anconeus muscle in the extension region may be controlled inhibitorily. While activity of the long head of triceps brachii muscle was less than 10% for all positions in the elbow valgus movement, activity of the anconeus muscle increased as the elbow reached extension position. The highest activity was seen at the elbow flexion of 10°, and its value reached around 50-60% of the maximum activity. Since the activity characteristics of the anconeus muscle were of the phase that was inverse to those of the extension movement, and furthermore activity of the long head of triceps brachii muscle during the valgus movement was an extremely low, the activity of the anconeus muscle at the elbow extension position is not activity for extension movement but is activity for valgus movement, we presumed.

The extension movement of the elbow obtained by electrical stimulation to anconeus muscle did not reach full extension. Moreover, the extension torque obtained by electrical stimulation decreased as the elbow reached extension range, and ultrasound imaging at the elbow flexion of 10° revealed the valgus movement, not extension. Judging from the above, it was inferred that the elbow extension function considered as a main effect of the anconeus muscle is of the elbow flexion angles up to around 45°. Its reasons include anatomical features of anconeus muscles. The anconeus muscles have an origin in lateral epicondyle and are unipennate muscles which attach to ulna widely in a fan-like form. Their pinnate angle is small in distal parts, muscular fibers are arranged in the vertical direction, and the pinnate angle is large in the proximal part and the muscular fibers are arranged in the horizontal direction [7,8,20]. In other words, the muscular fibers of the distal part shorten in the elbow extension position, and the tension becomes low as a result. On the other hand, the muscular fiber length of the proximal part is not influenced by the flexion and extension positions of the elbow, and therefore it was supposed that almost constant tension is maintained. Therefore, it was presumed that this muscular fiber structure of anconeus muscles influenced the results shown by measurement of the torque and observation of ultrasound imaging during the electrical stimulation in this study. Moreover, we presumed that the distal part of anconeus muscles may have involved in elbow extension and the proximal part in valgus movement.

Analyzing functions of the anconeus muscle comprehensively from muscular activity and dynamics of the elbow joint by electrical stimulation, we presumed that the anconeus muscle functioned as an extension muscle in the flexion region of an elbow and as a valgus muscle in the extension region and activity caused by each movement was controlled rationally.

Conclusion

In this study, the authors derived EMGs for the purpose of elucidating a braking function for varus movement of the anconeus muscle in detail. Moreover, the electrical stimulation was given to anconeus muscles, elbow joint extension torque was measured, and dynamics of humerus and ulna was observed by ultrasound imaging. The result revealed that activity of the anconeus muscle of the extension increased in an elbow flexion region and that of the valgus increased in an extension region. Moreover, it has been clarified that the extension torque by the electrical stimulation to the anconeus muscle hardly occurs in the extension region. It has been judged from these results that the main roll of the anconeus muscle is a valgus function, a braking function for varus movement in other words, in the elbow joint extension region.

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Conflicts of Interest

There are no companies having COI relationship with the authors that need be disclosed.

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