Electromyographic Study of the Elbow Flexors and Extensors in a Motion of Forearm Pronation/Supination while Maintaining Elbow Flexion in Humans

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Naito, A., Sun, Y.-J., Yajima, M., Fukamachi, H. and Ushikoshi, K. Electromyographic Study of the Elbow Flexors and Extensors in a Motion of Forearm Pronation/Supination while Maintaining Elbow Flexion in Humans. Tohoku J. Exp. Med., 1998, 186 (4), 267–277 — Activities of the elbow flexors (biceps brachii, BB; brachialis, B; brachioradialis, BR) and extensors (triceps brachii, TB) in a motion of forearm pronation/supination with maintenance of elbow flexion (PS-movement) in nine healthy human subjects were studied by electromyography (EMG). The subject performed the PS-movement slowly or quickly with or without a load extending the elbow. In the slow PS-movement, an increase and decrease of EMG activities during supination and pronation, respectively, were seen in BB and the reverse was in B. A clear increment of EMG activities in BB accompanied with a reduction of EMG activities in B and/or BR, and the reverse were often observed. The contraction level and gain with the forearm supine were higher and larger than those with the forearm prone, respectively, in BB and the reverse was in B and BR. In a series of the quick PS-movement, alternating increases of EMG activities between BB and the other flexors (B and BR) were seen. Since TB showed no EMG activities throughout the experiment, it is suggested that reciprocal contractions between BB and the other flexors, which produce a complementary force in flexion direction, enable motions of pronation/supination with maintenance of flexion. Contraction properties of the flexors were discussed. ——— electromyography (EMG); humans; elbow flexors and extensors; pronation/supination; reciprocal contraction
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The elbow joint, which consists of the humero-ulnar, humero-radial and superior radio-ulnar joints in a common capsule (Basmajian 1982), participates in
motions of elbow flexion/extension and forearm pronation/supination in humans. In the elbow flexors, the biceps brachii (BB) contributes to flexion and supination, and the brachialis (B) and brachioradialis (BR) contribute to flexion. Several studies with electromyography (EMG) showed that BB and the other flexors (B and BR) contracted reciprocally during isometric contraction with force in the pronation/supination direction (Cnockaert et al. 1975; Gielen and von Zuylen 1986; von Zuylen et al. 1988; Buchanan et al. 1989; Hebert et al. 1991; Caldwell et al. 1993; Jamison and Caldwell 1993). Our previous EMG study also showed reciprocal contractions between BB and the other flexors (B and BR) during a dynamic motion of pronation/supination while maintaining elbow flexion (PS-movement) (Naito et al. 1995). In our study, however, we examined the phenomenon only in one subject and provided no information on activities of the elbow extensors. In the present study, we investigated activities of the flexors and extensors in the PS-movement with EMG. Also an apparatus, which enabled us to give a constant torque in extension direction throughout the movement, was used for the study.

**Subjects and Methods**

EMGs of the elbow flexors and extensors were recorded in nine healthy human subjects (six males and three females, age range 22-34 years), all of whom gave their informed consent to the experimental procedure, which was approved by the Ethics Committee of Shinshu University School of Medicine. During the experiment, a subject was sitting on a chair and keeping the upper arm on a table with the shoulder flexed to about 90 degrees (Fig. 1).

Bipolar wire electrodes were implanted percutaneously into the flexors (the long and short heads of BB [BL and BS, respectively] B, and BR) and extensors (the lateral head of the triceps brachii, TL). Experimental procedures for EMG recording have been fully described in our previous report (Naito et al. 1994a). EMGs were amplified, rectified and averaged for the analysis.

A movement tested was a to-and-fro motion from prone to supine position of the forearm while maintaining the elbow joint (PS-movement) in 30, 60 and 90 degrees of flexion. The subject performed the PS-movement slowly or quickly with or without a load extending the elbow (torque: 1.2, 2.4, 3.6, 4.8, 6.0, 7.2 Nm) (Fig. 1). Since the length of the forearm (moment arm) varied from subject to subject (ranged between 22.5 and 25.0 cm), the torque was adjusted by changing the weight of the load in each subject. In the slow PS-movement, each motion of supination and pronation was started at an experimenter's call and finished in about 5 seconds. The subject kept the forearm prone before supination and after pronation, and supine after supination for more than 5 seconds. Therefore the slow PS-movement, for which approximately 30 seconds were taken, was divided into the following five phases. P1 phase (more than 5 seconds): The forearm was kept prone before supination. Sup phase (about 5 seconds): The subject was
Fig. 1. Experimental situation of electromyogram (EMG) recording. The subject was sitting on a chair and keeping the upper arm on a table with the shoulder joint flexed to about 90 degrees. The subject performed a to-and-fro motion from prone to supine position of the forearm (PS-movement) while maintaining elbow flexion (30, 60 and 90 degrees of flexion). When the PS-movement with a load extending the elbow was examined, the load (a: 1.2, 2.4, 3.6, 4.8, 6.0, 7.2 Nm), which pulled the distal end of the forearm (around the ulnar and radial styloid processes) perpendicular to the forearm axis through two pulleys (b, c) and a wrist belt (d), was used. A potentiometer (e) was employed to indicate changes in the position of the forearm.

S phase (more than 5 seconds): The forearm was kept supine. Pro phase (about 5 seconds): The subject was pronating the forearm. P2 phase (more than 5 seconds): The forearm was kept prone after pronation. In the quick PS-movement, a series of five to ten PS-movements were started at the call and finished in 20 to 60 seconds (frequency: 10 to 40 times per minute). The slow PS-movement was examined in all the nine subjects and the quick PS-movement was in three subjects. The movement was performed more than two times in each experimental situation. A potentiometer was used for indicating changes in the position of the forearm (Fig. 1).

Amplitudes of averaged EMGs in the muscles during the P1 and S phases in the slow PS-movement were measured using a digitizer (KD4300, Graphtec Co., Tokyo). For standardization, contraction levels of a muscle during the P1 and S phases were indicated by expressing the amplitudes as a percentage of the amplitude of averaged EMG produced by the maximal voluntary contraction of the muscle (%Max). We checked that the amplitude by the maximal contraction scarcely changed by changing the position of the forearm. The data were subject-
ed to statistical analysis using paired t-test and using a method for an examination of significant differences among regression lines (Snedecor and Cochran 1967).

Results

Slow PS-movement

Figs. 2 and 3 show averaged EMGs of the elbow flexors and extensors in the slow PS-movement under various experimental situations in two subjects. In BB (BL and BS), EMG activities were seen during the S phase under every experimental situation. In the movement without the load and with a small torque of the load, slight or no EMG activities were seen during the P1, Sup, Pro, and P2 phases. In the movement with a large torque of the load, an increase and decrease of EMG activities were seen during the Sup and Pro phases, respectively. A remarkable increment of EMG activities around the S phase was often observed. In B, EMG activities continuously appeared throughout the movement even without the load under every experimental situation. A decrease and increase of EMG activities were seen during the Sup and Pro phases, respectively. In BR, slight or no EMG

Fig. 2. Averaged EMGs of the elbow flexors (the long and short heads of the biceps brachii: BL and BS, the brachialis: B, the brachioradialis: BR) and extensors (the lateral head of the triceps brachii: TL) during slow PS-movements with or without a load (2.4 Nm and 7.2 Nm) in a subject (Y.Y., female, 22 years old). The subject performed the movements at 30, 60 and 90 degrees flexion of the elbow joint. Solid lines indicate changes in position of the forearm in this as well as those in Figs. 3 and 6. Clear reductions of EMG activities in B or BR accompanied with increases of those in BL or BS are observed (arrowheads). Abbreviations in this as well as in Figs. 3 to 6. Note that TL shows no EMG activities throughout the movements.
activities were seen throughout the movement without the load and with a small torque of the load. When EMG activities appeared in the movement with a large torque of the load, they were seen to be nearly regular during the P1, Sup, Pro, and P2 phases. A remarkable reduction of EMG activities around the S phase was often observed. Among the flexors, a clear increment of EMG activities in BB (BS and/or BL) accompanied with a reduction of EMG activities in B and/or BR (arrowheads in Figs. 2 and 3) and the reverse were often observed. On most occasion, only B showed EMG activities during the P1 or P2 phases in the movement without the load and with a small torque of the load. In TL, no EMG activities were seen throughout the movement under every experimental situation.

Fig. 4 shows the contraction level (mean ± s.d.) of the flexors during the P1 and S phases under every experimental situation. Fig. 5 illustrates the linear correlation between the contraction level and torque of the load during the P1 and S phases with the elbow joint at 30, 60, and 90 degrees of flexion. The height and slope of the regression line for the S phase are higher and steeper than those for the P1 phase, respectively, in BB ($p<0.01$) and the reverse is in B and BR ($p<0.01$ or 0.05) except the height at 90 degrees of flexion in BR. Thus the contraction level and gain for the S phase were higher and larger than those for the P1
Fig. 4. Contraction levels of the elbow flexors (BL, BS, B and BR) during the P1 and S phases in the slow PS-movement under every experimental situation. Abscissa: torque of the load extending the elbow (Nm). Ordinate: contraction level indicated by expressing the amplitude of averaged EMG as a percentage of the amplitude produced by the maximal voluntary contraction (%Max). Each column (P1 phase: open column, S phase: hatched column) in the graphs represents mean±s.d. of the data from the nine subjects. Significant difference of the contraction levels between the P1 and S phases are marked with asterisks (*p < 0.05, **p < 0.01).

phase, respectively, in BB, and the reverse was in B and BR. The deeper flexion angle of the elbow, the lower contraction level and smaller gain for the P1 phase in all the muscles (p < 0.01 or 0.05) and for the S phase in BS (p < 0.05) and the lower contraction level and larger gain for the S phase in BL (p < 0.05). The constant term of the regression equation is plus for the S phase and minus for the P1 phase in BB, plus for the S and P1 phases in B, and minus for the S and P1 phases in BR.

Quick PS-movement

Fig. 6 shows averaged EMGs of the flexors and extensors in a series of the quick PS-movement in two subjects. Among the flexors, EMG activities of BB (BL and BS) increased with increasing a degree of supination, whereas those of B and BR increased with increasing a degree of pronation. These fluctuations resulted in alternating increases of EMG activities between BB and the other flexors under every experimental situation. TL showed no EMG activities throughout the movement as well as in the slow PS-movement.

Discussion

The present study showed activities of the elbow flexors and extensors in the
Fig. 5. Correlation between the contraction level of the elbow flexors (BL, BS, B and BR) and the torque of the load during keeping the P1 and S phases in the slow PS-movement with maintenance of the elbow joint at 30, 60 and 90 degrees of flexion. Each regression line (P1 phase: solid line; S phase: broken line) in the graphs is drawn on the data from the nine subjects (A1: \(y = 2.49x - 0.90, r = 0.61\); A2: \(y = 3.91x + 13.36, r = 0.52\); B1: \(y = 1.50x - 1.48, r = 0.56\); B2: \(y = -5.05x + 4.02, r = 0.68\); C1: \(y = 0.82x - 1.04, r = 0.54\); C2: \(y = 5.28x + 3.28, r = 0.67\); D1: \(y = 2.41x - 1.47, r = 0.46\); D2: \(y = 4.15x + 4.81, r = 0.54\); E1: \(y = 1.19x - 1.47, r = 0.46\); E2: \(y = 3.40x + 1.50, r = 0.56\); F1: \(y = 0.58x - 0.82, r = 0.44\); F2: \(y = 2.82x + 3.46, r = 0.52\); G1: \(y = 5.68x + 13.38, r = 0.81\); G2: \(y = 4.19x + 6.92, r = 0.77\); H1: \(y = 5.69x + 8.89, r = 0.81\); H2: \(y = 4.20x + 5.77, r = 0.71\); I1: \(y = 5.00x + 6.63, r = 0.74\); I2: \(y = 4.40x + 3.35, r = 0.74\); J1: \(y = 4.34x - 3.18, r = 0.73\); J2: \(y = 1.93x - 2.04, r = 0.52\); K1: \(y = 3.86x - 2.73, r = 0.78\); K2: \(y = 1.73x - 0.45, r = 0.54\); L1: \(y = 2.85x - 2.56, r = 0.76\); L2: \(y = 1.69x - 0.91, r = 0.50\)). The contraction level during both the P1 and S phases correlated closely with the torque at every elbow angle in all the muscles \((r, p < 0.001)\). Significant differences in height and slope of the regression lines between the P1 and S phases at each flexion angle are marked with triangles (\(\bullet\), \(p < 0.01\); \(\circ\), \(p < 0.05\)) and squares (\(\blacksquare\), \(p < 0.01\); \(\square\), \(p < 0.05\)), respectively. Ordinate and abscissa as Fig. 4.

PS-movement with EMG. In the slow movement, an increase and decrease of activities during supination and pronation, respectively, were seen in BB and the reverse was in B. A clear increment of activities in BB accompanied with a reduction of activities in B and/or BR and the reverse were often observed. In a series of the quick movement, alternating increases of activities between BB and the other flexors (B and BR) were seen. Consequently reciprocal contractions between BB and the other flexors occur not only in a static condition (Cnockaert et al. 1975; Gielen and von Zuylen 1986; von Zuylen et al. 1988; Buchanan et al. 1989; Hebert et al. 1991; Caldwell et al. 1993; Jamison and Caldwell 1993) but also in a dynamic motion of pronation/supination (Naito et al. 1995). In the present study, TL showed no EMG activities throughout the experiment. In the
Fig. 6. Averaged EMGs of the elbow flexors (BL, BS, B and BR) and extensors (TL) during a series of the quick PS-movement in two subjects (a: Y.Y., female, 22 years old; b: Y.Y., male, 23 years old). Alternating increases of EMG activities between the biceps brachii (BL and BS) and the other flexors (B and BR) are observed. TL shows no EMG activities during the movements.

The elbow flexors differ in their activities in the positions of the forearm (Basmajian and Deluca 1985). Basmajian and Latif (1957) reported that during maintenance of flexion B was active and BR was inactive in all positions of the forearm, and BB was active in the supine position and inactive in the prone position. They showed that during flexion with a load (1.2 kg) BR was moderately active in the prone or semiprone positions but slightly active in the supine
position. In the present study, correlation between the contraction level and torque was represented by regression lines. The contraction level (height of the line) in the supine position (the S phase) was higher than that in the prone position (the P1 phase) in BB and the reverse was in B and BR. The constant term of the regression equation was plus in the supine position and minus in the prone position in BB, plus in the prone and supine positions in B, and minus in the supine and prone positions in BR. These findings consistent with the observations of Basmajian and Latif (1957). In the present study, the contraction gain (slope of the line) in the supine position was larger (steeper) than that in the prone position in BB and the reverse was in B and BR. As far as we know, no reference to such observations are found in the literature. On the other hand, reciprocal inhibition in the human upper limb has been studied (Day et al. 1984; Katz et al. 1991; Aymard et al. 1995; Miyasaka et al. 1995, 1996, 1997; Naito et al. 1996, 1998). Katz et al. (1991) showed reciprocal inhibition between BB and TB. However, since TB showed no activities in the PS-movement, BB must receive no inhibition from TB. Recently, we have demonstrated reciprocal inhibition between BB and BR (Miyasaka et al. 1995; Naito et al. 1996), and between BB and the pronator teres (PT) (Miyasaka et al. 1996, 1997; Naito et al. 1998). Since BB and PT contract reciprocally in the PS-movement (Naito et al. 1998) as well as BB and BR, the inhibition from BR and PT to BB, and the reverse must occur alternately in the movement. Probably such neural projections partly contribute to reciprocal changes in contraction level and gain between BB and the other flexors.

BB has been often employed in EMG studies of the elbow flexors in humans, because its EMGs can be easily recorded with surface electrodes. However, the present EMG study with intramuscular electrodes clearly showed differences of activities among the flexors. It therefore must be kept in mind that activities of one flexor dose not represent activities of the other flexors in humans.

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References


