Journal of Biomechanics xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Muscle activity during maximal isometric forearm rotation using a power grip

Joseph Bader[a], Michael R. Boland[b,c,d,*], Desney Greybe[d], Arthur Nitz[e], Timothy Uhl[e], David Pienkowski[a,b]

[a] Orthopaedic Biomechanics Laboratory, Center for Biomedical Engineering, University of Kentucky, Lexington, KY, United States
[b] Department of Orthopaedic Surgery, University of Kentucky Medical Center, Lexington, KY, United States
[c] Hand Institute, Auckland, New Zealand
[d] Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand
[e] Department of Rehabilitation Sciences, University of Kentucky, Lexington, KY, United States

ARTICLE INFO

Article history:
Accepted 7 December 2017
Available online xxxx

Keywords:
Activation
Electromyography
Forearm
Muscle
Pronation
Supination

ABSTRACT

This study aimed to provide quantitative activation data for muscles of the forearm during pronation and supination while using a power grip. Electromyographic data was collected from 15 forearm muscles in 11 subjects while they performed maximal isometric pronating and supinating efforts in nine positions of forearm rotation. Biceps brachii was the only muscle with substantial activation in only one effort direction. It was significantly more active when supinating (μ = 52.1%, SD = 17.5%) than pronating (μ = 5.1%, SD = 4.8%, $p < .001$). All other muscles showed considerable muscle activity during both pronation and supination. Brachioradialis, flexor carpi radialis, palmaris longus, pronator quadratus and pronator teres were significantly more active when pronating the forearm. Abductor pollicis longus and biceps brachii were significantly more active when supinating. This data highlights the importance of including muscles additional to the primary forearm rotators in a biomechanical analysis of forearm rotation. Doing so will further our understanding of forearm function and lead to the improved treatment of forearm fractures, trauma-induced muscle dysfunction and joint replacements.

1. Introduction

The ability to grip an object and rotate forcefully is a major function of the forearm/wrist/hand complex. Yet, of the upper limb's many functions, the generation of pronosupination torque that can be transmitted to the hand is the most poorly understood (Matsuoka et al., 2006). Forearm torque occurs about an axis that passes through the ulnar head distally and the radial head proximally (Matsuki et al., 2010; Nakamura et al., 1999). Consequently, healthy forearm rotation requires a normal ulna, ulnar head, radius and radial head and depends on normal neuromuscular function (Hagert, 1992).

Injury and dysfunction of the forearm is very common (Bronstein et al., 1997), leading to a reduced capacity to apply rotational torque. Suboptimal treatment has also been associated with significant complications, such as radioulnar impingement and distal radioulnar joint (DRUJ) instability (Ishii et al., 1998). Improved treatment for these conditions, especially those involving the DRUJ, requires an understanding of the forces to which the distal radius and ulnar head are exposed. In the upper limb, muscles are a key contributor to those loads (Chadwick and Nicol, 2000). Understanding muscle function is thus an important component for understanding forearm mechanics.

Brand and Thompson provided a unique understanding of musculotendon mechanics at the wrist (Brand and Thompson, 1981). Similar studies have been performed for the elbow (Murray et al., 2000). Mathematical models (Amis, Dowson, Wright, & Miller, 1979; Garner & Pandy, 2001; van der Heijden & Hillen, 1996; Werner & An, 1994) and mechanical joint simulators (Gofton et al., 2005; Gordon et al., 2006; Haugstvedt et al., 2001b; Werner et al., 1996) have also been used to investigate forces in the distal forearm. However, the way in which muscles contribute to forearm rotation has not been clearly established. Consequently, most of these methods have incorporated only a few forearm muscles, so that the accuracy of the models is questionable.

It is widely accepted that the biceps brachii (BB), supinator (SUP), pronator quadratus (PQ) and pronator teres (PT) muscles are predominantly responsible for forearm pronation and

* Corresponding author at: Hand Institute, 212 Wairau Road, Glenfield, Auckland 0627, New Zealand.
E-mail address: michael@handsurgeon.co.nz (M.R. Boland).

https://doi.org/10.1016/j.jbiomech.2017.12.011
0021-9290/© 2017 Elsevier Ltd. All rights reserved.

supination (Basmajian and De Luca, 1985; Haugstvedt et al., 2001a; O'Sullivan and Gallwey, 2005; Winters and Kleweno, 1993). Yet, many other muscles cross the forearm's axis of rotation and have the capacity to influence forearm rotation. Moment arm data for these muscles is limited and varies considerably between studies (An et al., 1981; Bremer et al., 2006; Ettema et al., 1998). There is also evidence that muscle moment arms in the forearm may be highly sensitive to the forearm's axis of rotation (Greybe et al., 2016) and change with upper limb posture (An et al., 1981; Ettema et al., 1998). Therefore, it remains difficult to know how these muscles influence forearm rotation or whether they should be included in analyses of DRUJ mechanics.

Electromyography (EMG) is a useful tool for investigating muscle function and, as a measure of muscle activation, is an important component in many musculoskeletal models (Buchanan et al., 2004; Gagnon et al., 2011; Nikooyan et al., 2012). However, relatively few studies have examined the activation of upper limb muscles during forearm rotation. The data that does exist is limited primarily to BB, brachialis (BRA) and brachioradialis (BRAR) (Basmajian and Latif, 1957; Boland et al., 2008; de Sousa et al., 1961; Naito et al., 1998; Naito et al., 1995), with a few studies also including the extensor carpi radialis brevis (ECRB), PQ, PT or SUP (Basmajian and Travill, 1961; Gordon et al., 2004; O'Sullivan and Gallwey, 2002). This makes the development of realistic forearm mechanics models problematic, since we do not know which muscles are active, nor to what extent they are active. A more comprehensive set of EMG data is needed, to allow a more complete understanding of muscle activity during forearm pronation and supination.

Therefore, the purpose of this study was to quantify the activation of 15 muscles in the forearm while generating maximal isometric pronation and supination torques in a range of forearm postures. Since resisted forearm rotation is rarely performed in isolation, it was combined with a power grip to provide muscle activations that are more functionally realistic. Napier defined the power grip as the posture of the hand when force application is of primary importance – it involves gripping an object with the hand in the form of a clenched fist (Napier, 1956). Differences in muscle activation were evaluated between effort directions and forearm positions. It was hypothesised that BB and SUP would be significantly more active when supinating the forearm and that PQ and PT would be significantly more active when pronating the forearm, regardless of forearm posture. Where additional muscles are preferentially activated, it was hypothesised that this preference may be posture dependent.

2. Methods

2.1. Study design

Institutional Review Board approval was gained for a laboratory study of EMG muscle activity in normal adults during maximal forearm rotation using a power grip. Subjects were examined by a physician to ensure that no forearm or wrist pathology existed and excluded if they had prior forearm/wrist/elbow surgery or injury, arthritis involving the elbow or wrist, neurologic disorders, or aversion to needles. Fifteen forearm muscles were studied using fine-wire electrodes. To prevent electrode interference, the study was divided into four sub-studies (Table 1). The right forearms of 11 subjects were used in each, with some subjects volunteering for more than one sub-study. All participants were right hand dominant.

Muscles were included based on the following criteria: (1) muscles known to primarily function in forearm rotation; (2) muscles that cross the longitudinal axis of the forearm and therefore have a potential role in DRUJ loading and (3) muscles acting across the elbow that could potentially contribute to forearm pronosupination torque (Buchanan et al., 1989; van Zuylen et al., 1988). The following 15 muscles were analysed: abductor pollicis longus (APL), biceps brachii (BB), brachialis (BRA), brachioradialis (BRAR), extensor carpi radialis brevis (ECRB), extensor carpi radialis longus (ECRL), extensor carpi ulnaris (ECU), extensor indicis proprius (EIP), extensor pollicis longus (EPL), flexor carpi radialis (FCR), flexor carpi ulnaris (FCU), palmaris longus (PL), pronator quadratus (PQ), pronator teres (PT) and supinator (SUP).

2.2. Experimental protocol

The muscles of interest were isolated anatomically using published guidelines (Perotto, 1994). Two sterile, bipolar, Teflon-insulated, 50 μm fine-wire electrodes (California Fine Wire Co., Grover Beach, CA) with 3 – 5 mm exposed tips were inserted 1 cm apart in the muscle of interest using a two-needle, sterile insertion technique (Kelly et al., 1997). A grounding surface electrode was placed on the acromion. For each muscle, a five second baseline data set was collected with the subject's arm relaxed, followed by a maximal voluntary isometric contraction (MVIC) designed to elicit maximal activation in the relevant muscle (Kendall et al., 2005). Each MVIC was performed three times and held for five seconds with a two minute rest interval between trials.

The experimental setup is shown in Fig. 1. Trials were performed with subjects standing and gripping the handle of a dynamometer (BTE Technologies, Hanover, MD). The procedure was standardised by: adjusting the height of the dynamometer so that the subject's forearm was horizontal and their elbow was flexed at 90° (Bechtel and Caldwell, 1994; Buchanan et al., 1989); placing an abduction pillow under the upper arm to maintain a humerus that was vertical to the ground; marking the foot position and maintaining it between trials. Subjects were instructed to maintain a neutral wrist relative to the forearm and this was monitored visually.

The handle of the dynamometer was randomly placed in one of nine positions: neutral, 25°, 50°, 75° and maximum pronation and supination (N, P25, P50, P75, Pmax, S25, S50, S75 and Smax). The maximum pronation and supination positions were measured using a protractor (Craftsman Tools, Sears Brands LLC., Hoffman Estates, IL). Three times in each position, the subject gripped the handle of the dynamometer and pronated the forearm with as much isometric force as was comfortably possible for five seconds. The subject then repeated the three trials while exerting a maximal isometric supinating effort. These tasks resulted in a total of 54 pronation-supination trials per subject. A two minute rest interval

Table 1
Muscles and subjects in sub-studies.

Group	Muscles	Subjects	Male	Female	Mean age (SD)	Repeats
1	APL, ECU, FCU	11	7	4	26.3 (2.5)	0
2	BB, ECRB, EPL, FCR	11	8	3	25.6 (3.2)	6
3	ECRL, EIP, PT, SUP	11	6	5	26.5 (2.6)	9
4	BRA, BRAR, PL, PQ	11	6	5	26.4 (3.1)	9

Please cite this article in press as: Bader, J., et al. Muscle activity during maximal isometric forearm rotation using a power grip. J. Biomech. (2017), https://doi.org/10.1016/j.jbiomech.2017.12.011