ANALYSIS OF MUSCLE ACTIVITY DURING CONTRACTIONS IN THE THREE HEADS OF THE TRICEPS BRACHII USING SURFACE ELECTROMYOGRAPHY

by

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LIST OF ABBREVIATIONS

ADC	-	Analog-to-Digital Converter
ACC	-	Asian Cricket Coach
Ag/AgCl	-	Silver/Silver Chloride
ANOVA	-	Analysis of Variance
BC	-	Back foot contact
BR		Ball release
cm	-	Centimeter
CMRR	-	Common-mode rejection ratio
CV	-	Coefficient of variation
EMG	-	Electromyography
FB	-	Fast bowling
FC	-	Front foot contact
FD	-	First 5-s duration
FT	-	Follow through
Hz	-	Hertz
ICC	-	International Cricket Council
kg	-	Kilogram
km/h	-	Kilometer per hour
LD	-	Last 5-s duration
MB	-	Mid bound
mm	-	Millimetre
MPF	-	Median power frequency

MREC	-	Medical Research and Ethics Committee
ms	-	Millisecond
MVC	-	Maximal voluntary contraction
MVIC	-	Maximum voluntary isometric contraction
PS	-	Pre delivery stride
RBD	-	Randomized Block Design
RMS	-	Root mean square
RU	-	Run-up
SB	-	Spin bowling
SD	-	Standard deviation
sEMG	-	Surface electromyography
TB	-	Triceps brachii

LIST OF SYMBOLS

μ	-	Mu
τ	-	Tau
β	-	Beta
ε	-	Epsilon
η	-	Eta
α	-	Alpha
Ω	-	Ohm
MΩ	-	Megaohm
pF	-	Picofarads
μV	-	Microvolts
mV	-	Milivolts
V	-	Volts
p	-	Probability value for hypothesis testing
s	-	Second
y	-	Year
min	-	Minutes

Analisis Aktiviti Kontraksi Otot pada Tiga Bahagian Triceps Brachii dengan Menggunakan Elektromiografi Permukaan

ABSTRAK

Antara semua otot rangka hujung atas, tiga kepala (sisi, panjang dan medial) triceps brachii (TB) dianggap sebagai otot yang paling bertanggungjawab untuk aktiviti normal dan sukan. Dalam kajian ini, kami mencatatkan dan menilai aktiviti otot di antara ketiga-tiga kepala TB menggunakan isyarat Electromyography permukaan (EMGp) semasa pengecutan isometrik dan isotonik. Sistem perolehan data Delsys dan PowerLab Yang boleh didapati secara komersial telah digunakan untuk merakam isyarat EMG. Pengecutan isometrik dihasilkan oleh aksi pegangan kuat dengan sambungan penuh siku. Dua protokol yang berbeza telah digunakan - penguncupan isometrik berulang dan penguncupan isometrik berpanjangan. 13 peserta melakukan 5 percubaan, 10 s setiap satu, untuk memerhatikan tingkah laku diantara dan didalam pengecutan, dan 18 peserta melakukan percubaan tunggal 90 s untuk memerhatikan kesan keletihan. Selain itu, pengecutan isotonik disiasat semasa aktiviti kriket bowling. Dua kategori kriket bowling yang berbeza telah dikaji - bowling pantas dan bowling pusing. 10 peserta melakukan 3 pengambilalihan (1 pengambilalihan = 6 bola penghantaran) bersamaan dengan 18 ujian untuk kedua-dua bowling pantas dan bowling pusing. Untuk analisis statistik, kami mengira nilai purata daripada root mean square (RMS) normal daripada data yang dikumpulkan daripada semua peserta. Kami mendapati aktiviti otot di antara ketiga-tiga kepala TB, antara pengecutan isometrik berulang, mempunyai statistik yang signifikan ($p < 0.05$). Aktiviti otot menurun pada kepala sisi dan panjang, walaubagaimanapun ia meningkat di kepala medial. Pada kes antara pengecutan pula, kekuatan otot TB menurun dengan peningkatan tempoh penguncupan, dan penurunan yang paling rendah pula diperhatikan pada kekuatan otot di kepala medial. Hasil daripada penguncupan isometric yang berpanjangan menunjukkan penurunan beransur-ansur pada purata yang dikira daripada nilai RMS normal pada semua peserta selepas tempoh masa yang tertentu, menunjukkan kehadiran keletihan. Masa untuk kehadiran keletihan diperhatikan di kepala sisi, panjang dan medial masing-masing pada 50 s, 40 s dan 65 s. Kadar keletihan diperhatikan di kepala panjang, tengah dan sisi masing-masing pada cerun -2.863, -2.412 dan -1.877. Sebaliknya, semasa pengecutan isotonik, kami mendapati bahawa aktiviti sEMG antara tiga kepala TB dan antara 7 fasa bowling mempunyai statistik yang signifikan ($p < 0.05$). Antara kesemua 7 fasa, pengecutan fasa front-foot (FC) menjana aktiviti EMGp tertinggi dalam kedua-dua bowling pantas dan bowling pusing. Kami juga mendapati bahawa kesemua kepala TB yang lebih aktif di bowling pantas daripada bowling pusing. Selain itu, kepala medial didapati lebih aktif berbanding dengan kepala-kepala yang lain semasa kesemua 7 fasa bowling untuk kedua-dua bowling pantas dan bowling pusing. Hasil kajian ini boleh memainkan peranan penting dalam usaha kami untuk lebih memahami fisiologi dan biomekanik otot TB.

Analysis of Muscle Activity during Contractions in the Three Heads of the Triceps Brachii using Surface Electromyography

ABSTRACT

Among all the upper extremity skeletal muscles, the three headed (lateral, long and medial) triceps brachii (TB) is considered as the muscle most responsible for normal and sports activities. In this research, we recorded and evaluated muscle activity among the three heads of TB, using surface electromyography (sEMG) signals, during isometric and isotonic contractions. The commercially available Delsys and PowerLab data acquisition systems were used to record the EMG signals. Isometric contractions were produced by a forceful handgrip task with full elbow extension. 2 different protocols were applied – repetitive isometric contraction and prolonged isometric contraction. 13 participants performed 5 trials, 10 s each, to observe behavior between and within contractions, and 18 participants performed a single trial of 90 s to observe fatiguing effects. On the other hand, isotonic contractions were investigated during a cricket bowling action. 2 different bowling categories were studied – fast bowling (FB) and spin bowling (SB). 10 participants performed 3 overs (1 over = 6 ball deliveries) equivalent to 18 trials for both FB and SB. For the statistical analysis, we computed the mean of the normalized root mean square (RMS) values across all subjects from the collected data. We found muscle activity among the three heads of TB, between repetitive isometric contractions, to be statistically significant ($p < 0.05$). Muscle activity decreased in the lateral and long heads, but however increased in the medial head. In the case of within contractions, TB muscle strength decreased with increasing contraction duration, and the lowest decrease of muscle strength was observed in the medial head. Results from the prolonged isometric contraction show a gradual decrease in the computed mean of the normalized RMS values across all subjects after a certain time period, indicating the presence of fatigue. Time to fatigue was observed at the lateral, long and medial heads at 50 s, 40 s and 65 s respectively. Fatiguing rates was observed at the long, medial and lateral heads at a slope of -2.863, -2.412 and -1.877 respectively. On the other hand, during the isotonic contractions, we found that the sEMG activities among the three heads of the TB and among the 7 phases of bowling to be statistically significant ($p < 0.05$). Among the 7 phases, the front-foot contract (FC) phase generated the highest sEMG activity during both FB and SB. We also found that all the heads of the TB were more active in FB than SB. Moreover, the medial head was found to be more active compared to the other heads during all the 7 phases of bowling for both FB and SB. The outcomes of the present research may play a key role in our quest to better understand the physiology and biomechanics of the TB muscle.

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CHAPTER 1

INTRODUCTION

1.1 Background

The skeletal muscles of humans are made up of thousands of cylindrical muscle fibers often running all the way from origin to insertion. This skeletal muscles control the movement of various part of the human body including supporting the body, allowing motion, and protecting vital organs. Hence, a proper examination is required to investigate the skeletal muscle activities in order to identify different muscle conditions that arise from contractions. These skeletal muscle activities are commonly measured using Electromyography (EMG). EMG is a technique that has been widely accepted as a reliable tool to examine the condition of skeletal muscle activity during different motor tasks. This technique involves the recording of electrical activity produced in the skeletal muscle and is a useful tool to obtain information on the intensity of the neuromuscular impulses of the central nervous system (Gali-Muhtasib *et al.*, 2006). Generally, electrical activities of the skeletal muscle are measured using invasive EMG techniques or non-invasive EMG techniques. The invasive EMG technique consists of biopotential needle electrodes which are inserted into the skeletal muscle to allow detection of electric potentials close to the muscle fiber. But this technique cannot be used to obtain data that represents the whole muscle because it is only able to measure a small number of motor unit action potential (Giroux & Lamontagne, 1990; Kadaba *et al.*, 1985); whereas, the non-invasive EMG technique consists of biopotential surface electrodes which are placed over the skin surface of the skeletal muscle, and is able to measure a general motor unit action potential or a spatial characterisation of the electric potential distribution that represents the whole muscle (Jaggi *et al.*, 2009). The non-invasive EMG technique has become more popular for the investigation of skeletal muscle activities due to limitations in the invasive EMG technique and the easiness of electrode placement on the skin surface of the muscle. This non-invasive EMG technique is known as surface electromyography (sEMG). Recently, sEMG techniques have been utilized for the assessment of skeletal muscle activities in various application fields, including neuromuscular disorder assessment (Brændvik & Roeleveld, 2012; Huang & Ferris, 2009; Serrao *et al.*, 2012), physiological activity assessment in exercises (Koyama *et al.*, 2010; Plattner *et al.*, 2011; Sakamoto & Sinclair, 2012), physiological activity assessment in sports science (Lohse *et al.*, 2010; Neto & Magini, 2008; Rota *et al.*, 2012), and signal processing for prosthesis device control (Alkan & Günay, 2012; G. Li *et al.*, 2011). Thus, there is an increasing desire to understand the activity of skeletal muscles in the human body.

There are many types of skeletal muscles in the human body, and the triceps brachii (TB) muscle is the longest muscle among the skeletal muscles of the upper limb. The TB muscle is called a three headed muscle because there are three bundles of muscles, each of different origins and joining together at the elbow; where the three heads of the TB muscle are found to not work as a single unit throughout the extension/flexion movement (Landin & Thompson, 2011). Therefore, it is important to understand the activity in the heads of the TB muscle during various types of contractions so that the findings can help improve our understanding regarding the mechanisms of muscle activation which can be useful in various application fields, such as rehabilitation, sports science, physiological exercise, and signal processing for prosthesis device control.

1.2 Motivation of the Research

As mentioned earlier, sEMG techniques have been applied on skeletal muscles in order to identify their activity and the TB muscle has been of increasing interest in the last decade or so. For example, many researchers have used sEMG techniques and analysed the muscle activities of TB including muscle strength (Kim *et al.*, 2011; Rota *et al.*, 2012), muscle fatigue (D. Dearth *et al.*, 2010; Meszaros *et al.*, 2010; Missenard *et al.*, 2008; Stirn *et al.*, 2011), muscle force (Lindinger *et al.*, 2009; Salomoni & Graven-Nielsen, 2012), and motor unit action potential (Bottas *et al.*, 2010; Fang *et al.*, 2009). These activities of the TB muscle are generally investigated because of their importance in physiological exercise (Krentz & Farthing, 2010; Plattner *et al.*, 2011; Sakamoto & Sinclair, 2012), rehabilitation (Barker *et al.*, 2009; L. Li *et al.*, 2009; Serrao *et al.*, 2012), sports science (Lohse *et al.*, 2010; Neto & Magini, 2008; Rota *et al.*, 2012), and signal processing for prosthesis control applications (Alkan & Günay, 2012; Arslan *et al.*, 2010; G. Li *et al.*, 2011). Hence, it is clear that the TB muscle is considered an important muscle of the upper extremity, whose contractions needs to be monitored, due to its involvement in the fields of rehabilitation, physiological exercise, sports science, and prosthesis design. Thus, the different effects of contraction (isometric and isotonic) of the TB muscle, examined by comparing the muscle activity among the three heads of TB through sEMG signal analysis, is an important issue to be studied. To date, no previous study has investigated and compared muscle activity simultaneously among the three heads of TB in order to identify the effect of repetitive isometric contractions, muscle fatiguing effects during prolonged isometric contractions, and their behavior during isotonic contractions in a sports movement such as cricket bowling.

1.3 Problem Statement

The TB muscle is primarily involved in elbow extension as well as secondarily involved in other activities of the upper limb. To date, many researchers have addressed muscular function in a single head of the TB including lateral head (Barker *et al.*, 2009; Frère *et al.*, 2012a; VencesBrito *et al.*, 2011), long head (Kuhtz-Buschbeck & Jing, 2012; Louis & Gorce, 2010), and medial head (Emery & Côté, 2012). On the other hand, a number of studies have investigated the muscular function simultaneously in two heads of TB including lateral and long heads (Janssen-Potten *et al.*, 2008), long and medial heads (Falvo *et al.*, 2009), and medial and lateral heads (Yung *et al.*, 2012). But previous studies indicate that the three heads of TB do not work as a single unit throughout the elbow extension/flexion. Thus, it is important to understand the role of every single head of the TB muscle when performing repetitive tasks and prolonged tasks in normal activities, as well as during rapid sports activities. Therefore, the present study aims to examine and compare muscle activity among the three heads of the TB during repetitive isometric contraction – full elbow extension with hand grip force exercise, prolonged isometric contraction – full elbow extension with hand grip force exercise, and during rapid isotonic contraction in a cricket bowling action. These protocols for these activities are designed and investigated in the present study to answer a few interrelated research questions.

1.4 Research Questions

The following research questions are posed regarding the simultaneous activity of the three heads of TB:

i) How does the muscle activity change in the three heads of TB with repetitive isometric contractions?

ii) How does the muscle exhibit fatigue in the three heads of TB with prolonged isometric contraction?

iii) How does the muscle activity vary in the three heads of TB during rapid isotonic contractions (cricket bowling)?

1.5 Research Objectives

According to the research questions, the objectives of this work are as follows:

i) To evaluate the effect of repetitive isometric contractions in the three heads of the TB muscle.

ii) To examine and compare the muscle fatiguing conditions in the three heads of TB during prolonged isometric contractions.

iii) To investigate muscle activities in the three heads of TB during isotonic contractions when performing cricket bowling action.

1.6 Research Scope

This thesis focuses on the analysis of sEMG signals to discern muscle activity during contractions in the lateral, long, and medial heads of TB. As this intention is indeed very large, we intend to limit the scope of our research work within a well defined boundary in order to arrive at some tangible conclusions.

The type of examined muscle contractions and investigated muscle conditions has to be clearly set forth. Firstly, the effect of repetitive isometric contractions in the three heads of TB will be evaluated. Next, the fatiguing effect in the three heads of TB will be examined during prolonged isometric contractions. Lastly, from a practical point of view, we will analyze muscle activity in the three heads of TB during an application of rapid isotonic contraction in cricket bowling.

Secondly, we define the experimental setup used in our study. To evaluate the muscle activity of TB, we used a reliable commercial system for sEMG signal recording. All recorded sEMG signals were stored in a computer for subsequent offline analysis. A total of three (3) experimental protocols were conducted to investigate muscle activity in the lateral, long, and medial heads of TB during – repetitive isometric contraction, prolonged isometric contraction, and isotonic contraction in cricket bowling. We included only right handed dominant male participants between ages 22 to 34 years for all contractions. For repetitive isometric contractions, we recorded sEMG signals from 13 participants. 18 participants gave consent for the prolonged isometric contractions, whereas for the isotonic contractions in cricket bowling, we recorded sEMG signals from 10 participants for fast bowling and 10 participants for spin bowling.

Finally, since the research done in this work is a pilot study, our analysis will be limited to an initial investigation based on first order statistics for all the experiments conducted. It is our belief that, at this point of time, findings obtained from such statistical analysis is sufficient to provide interesting insights to the problem which may warrant further investigation by other researchers in the future.

1.7 Thesis Organization

This chapter has focused on the background of our research work, the motivations of the research, the problem statement and its significance, the main objectives, and the research scope. The next chapter will present the literature review on TB muscle anatomy and physiology, muscle activities of the TB during its various contractions and the application fields related to those TB muscle activities. In chapter 3, the details on the research methodology applied in the present research are presented including details of the participants, experimental protocol and procedures, sEMG signal recording and processing techniques, data analysis methods and procedures to investigate the muscle activity of TB. Following this, in chapter 4, the results are presented and discussed accordingly. We present our findings regarding the comparison of muscle activity in the three heads of TB for repetitive isometric contraction, prolong isometric contraction, and for isotonic contraction of fast and spin bowling in cricket. Finally, chapter 5 concludes the main findings and their significance. Major contributions of this research work and possible future directions of the research are also highlighted in this chapter.

CHAPTER 2

LITERATURE REVIEW

This chapter contains a review of the literature on the triceps brachii (TB) muscle and the different types of contraction mechanisms of this muscle in order to identify and discern muscle activity through sEMG. This chapter is divided into several parts. The first, second, and third parts address the TB muscle anatomy, TB physiology, and TB muscle contraction types respectively. The fourth part reviews the literature to identify and understand the previous related works on the analysis of muscle activity in the heads of TB during different types of contractions. The final part presents the previous works that have applied the findings of TB muscle activity in the fields of rehabilitation, sports science, physiological exercise, and signal processing for prosthesis device control.

2.1 Triceps Brachii Muscle Anatomy

The work done during elbow extension is performed by the TB muscle, which serves as a powerful extender of the forearm. This has been known for more than a century. Moreover, the TB muscle plays a role in stabilising the abducted glenohumeral joint by resisting the inferior displacement of the humeral head due to its bi-articular nature (Lin *et al.*, 2003). This bi-articular structure of the TB muscle indicates that its length must also be influenced by changes of torque direction (Buchanan *et al.*, 1986), and its contribution to elbow joint stability may reduce the risk of injury caused by sudden elbow loading (Holmes & Keir, 2012). One study (Arendt-Nielsen *et al.*, 1996) reports on the anatomical locations of TB muscle – the long head originates from the infraglenoid tubercle, the lateral head originates from the humerus superior to the radial groove and the lateral intermuscular septum, and the medial head extends from the humerus inferior to the radial groove and the medial intermuscular septum. However, the medial head is mostly covered by the lateral and long heads and is only visible closer to the elbow joint. Figure 2.1 shows the anatomical locations of the three heads of the TB muscle.

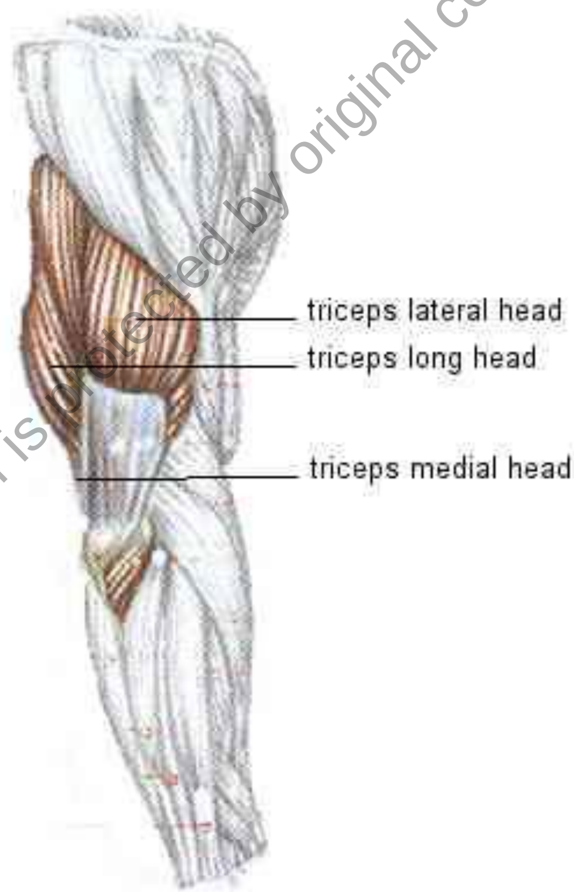

Figure 2.1: Anatomical Locations of the Three Heads of Triceps Brachii [Adopted from Google Image].