Monitoring muscle oxygenation and myoelectric activity after damage-inducing exercise

by

Sirous Ahmadi
BS (Nursing), MA (Exercise Physiology)

Thesis presented for the degree of Doctor of Philosophy
The University of Sydney
© 2007
Supervisors Statement

As supervisors of Sirous Ahmadi doctoral work, we certify his thesis ‘Monitoring muscle oxygenation and myoelectric activity after damage-inducing exercise’ to be suitable for examination.

Signed _____________________________
Date _____________________________
Associate Professor Glen M Davis

Signed _____________________________
Date _____________________________
Dr Peter J Sinclair

Discipline of Exercise and Sport Science,
Faculty of Health Sciences,
The University of Sydney
# Table of Contents

**Supervisors Statement** .................................................................................................................. ii  
**Abstract** ........................................................................................................................................ vii  
**Candidate Statement** .................................................................................................................. viii  
**Presentation of Work** ..................................................................................................................... ix  
**Prizes and awards** .......................................................................................................................... x  
**Acknowledgment** ........................................................................................................................... xi  
**Dedication** ....................................................................................................................................... xii  
**Preface** ........................................................................................................................................... xiii

## Chapter 1

**Introduction** ..................................................................................................................................... 1  
- Background ....................................................................................................................................... 2  
- Aims and objectives ............................................................................................................................. 3  
- Hypotheses ......................................................................................................................................... 4  
- Rationale ............................................................................................................................................ 4  
- Key Terminology ............................................................................................................................... 5  
- Abbreviations used in this thesis ......................................................................................................... 7  
- Conclusion .......................................................................................................................................... 9

## Chapter 2

**Review of Literature** ...................................................................................................................... 10  
- Introduction ....................................................................................................................................... 11  
- Muscle Oxygenation ........................................................................................................................... 11  
- Exercise and muscle damage .............................................................................................................. 14  
- Types of contractions .......................................................................................................................... 15  
- Theoretical mechanism(s) for exercise-induced muscle damage ..................................................... 16  
- Regeneration process after muscle damage ....................................................................................... 17  
- Possible interactions between muscle damage and oxidative metabolism .................................. 17  
- Signs and Symptoms of muscle damage ........................................................................................... 18  
- Methods of evaluating muscle damage ............................................................................................. 24  
- Biopsy ............................................................................................................................................... 24  
- Magnetic Resonance Imaging (MRI) .................................................................................................. 25  
- Ultrasonography ............................................................................................................................... 26  
- Electromyography (EMG) .................................................................................................................. 27  
- Near Infrared Spectroscopy (NIRS) .................................................................................................... 29  
- Summary ......................................................................................................................................... 51
# Chapter 3

Monitoring Muscle Oxygenation and Blood Flow after Eccentric Exercise-Induced Muscle Damage using Near Infrared Spectroscopy

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>54</td>
</tr>
<tr>
<td>Introduction</td>
<td>55</td>
</tr>
<tr>
<td>Methods</td>
<td>57</td>
</tr>
<tr>
<td>Statistical analysis</td>
<td>65</td>
</tr>
<tr>
<td>Results</td>
<td>65</td>
</tr>
<tr>
<td>Discussion</td>
<td>70</td>
</tr>
<tr>
<td>Conclusion</td>
<td>74</td>
</tr>
<tr>
<td>Acknowledgment</td>
<td>75</td>
</tr>
<tr>
<td>References</td>
<td>76</td>
</tr>
</tbody>
</table>

# Chapter 4

Electromyographic Activity of the Biceps Brachii after Exercise-Induced Muscle Damage

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>81</td>
</tr>
<tr>
<td>Introduction</td>
<td>82</td>
</tr>
<tr>
<td>Methods</td>
<td>84</td>
</tr>
<tr>
<td>Subjects</td>
<td>84</td>
</tr>
<tr>
<td>Study design</td>
<td>84</td>
</tr>
<tr>
<td>Eccentric exercise protocol</td>
<td>84</td>
</tr>
<tr>
<td>Resting assessments</td>
<td>85</td>
</tr>
<tr>
<td>Exercise assessments</td>
<td>86</td>
</tr>
<tr>
<td>Statistical analysis</td>
<td>88</td>
</tr>
<tr>
<td>Results</td>
<td>89</td>
</tr>
<tr>
<td>Discussion</td>
<td>94</td>
</tr>
<tr>
<td>Study limitations</td>
<td>99</td>
</tr>
<tr>
<td>Conclusion</td>
<td>100</td>
</tr>
<tr>
<td>Acknowledgement</td>
<td>100</td>
</tr>
<tr>
<td>References</td>
<td>101</td>
</tr>
</tbody>
</table>

# Chapter 5

Muscle Oxygenation after Downhill Walking-Induced Muscle Damage

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>105</td>
</tr>
<tr>
<td>Introduction</td>
<td>106</td>
</tr>
<tr>
<td>Materials and Methods</td>
<td>107</td>
</tr>
<tr>
<td>Subjects</td>
<td>107</td>
</tr>
<tr>
<td>Experimental procedures</td>
<td>108</td>
</tr>
<tr>
<td>Exercise assessments</td>
<td>114</td>
</tr>
<tr>
<td>Statistical Analyses</td>
<td>115</td>
</tr>
<tr>
<td>Results</td>
<td>115</td>
</tr>
</tbody>
</table>
References................................................................................................................... 181

Appendices................................................................................................................ 201

Appendix 1
Authors instructions for Applied Physiology, Nutrition and Metabolism .......... 202
Appendix 2
Authors instructions for Journal of Sports Science and Medicine (JSSM)........ 219
Appendix 3
Authors instructions for Clinical Physiology and Functional Imaging ............ 229
Appendix 4
Authors instructions for Isokinetics and Exercise Science ............................. 239
Appendix 5
Participant information and consent forms ...................................................... 244
Abstract

In this thesis, three experiments were conducted to monitor: (i) muscle oxygenation and electromyographic activity of the biceps brachii after exercise-induced muscle damage (ii) muscle oxygenation after downhill walking-induced muscle damage, and, (iii) muscle oxygenation following a bout of vigorous concentric exercise.

Maximal eccentric exercise (EE) of biceps brachii resulted in significantly increased mean resting oxygen saturation and decreased deoxyhaemoglobin. During isometric contractions at 50% and 80% of subjects’ maximum voluntary torque (MVT), oxygen desaturation and resaturation kinetics and volume were significantly decreased after EE, and these declines were significantly prevalent over the following 6 days. Additionally, a significant shift in median frequency intercept (measured by electromyography; EMG) towards lower frequencies was observed during isometric contractions at both 50% and 80% MVT after EE in the exercised arm.

After an exhaustive session of downhill walking, another form of EE, resting total haemoglobin and oxyhaemoglobin decreased. Furthermore, during isometric contractions at 30%, 50% and 80% of MVT, prolonged and significant increases were observed in oxygen desaturation and resaturation kinetics and volumes after ambulatory EE. In contrast to the two EE experiments, concentric contractions did not evoke any prolonged changes in muscle oxygenation.

Collectively, the findings of this thesis revealed significant and prolonged changes in muscle oxygenation at rest and during exercise, following sessions of strenuous eccentric exercise. Although not clear, the possible mechanism responsible for the changes in muscle oxygenation after EE could be increased resting muscle oxygen utilization due to probable muscle damage and a subsequent requirement of energy demanding repair processes. Concentric exercise resulted in fatigue, but it did not affect muscle oxygenation. Although a prolonged reduction in EMG median frequency intercept was observed after EE, this was not closely time-associated with the biochemical, anthropometric or functional markers of muscle damage.
Candidate Statement

I, Sirous Ahmadi, hereby declare that this submission is my own work and that it contains no material previously published or written by another person except where acknowledged in the text. Nor does it contain material, which has been accepted for the award of another degree.

In addition, ethical approval from the Human Research Ethics Committee of the University of Sydney was granted for the studies presented in this thesis. Participants were required to read a participant information document and informed consent was gained prior to data collection.

Name: Sirous Ahmadi

Signed ________________

Date ________________
Presentation of Work

Parts of the work presented in this thesis have been published and/or presented in the following forums:

Refereed articles


Proceedings


Prizes and awards

The author of this thesis was a scholarship holder funded by MSRT (Ministry of Science, Research and Technology), from the Iranian Government.
Acknowledgment

I would like to sincerely acknowledge the tremendous effort of Associate Professor Glen Davis in assisting and supervising me during the last four years. His kind attitude towards my family and I left no space for missing my home country, Iran. Thanks Glen!

I would like to thank Dr. Peter Sinclair, my co-supervisor, for his kind assistance and support on this thesis. I also want to thank Dr. Ché Fornusek, Mr. Ray Patton, Dr. Pat Ruell and Dr. Mari Clugston for their support throughout my PhD candidature.

I would also wish to express my appreciation to the people who volunteered as subjects for the experiments undertaken in this thesis. Thank you very much guys!

Finally and most importantly, I am very grateful to the wonderful support that I have received from my wife, Nasim. She never stopped helping me at both home and university, although she was struggling with her own studies. Also, the support that I received from my family overseas funded me a great courage towards continuing my studies and I truthfully appreciate that.
Dedication

I would like to dedicate this work to my daughter, Atria and my wife, Nasim. Since Atria’s birth during 2006, my spiritual life has changed and her smiles have made my life happier than ever.
Preface

This thesis is comprised of seven chapters. Chapter 1 provides an introduction and rationale for the studies presented in this thesis. Chapter 2 presents a review of literature on muscle oxygenation, muscle damage and the popular techniques for the assessment of muscle damage and oxygenation. Chapters 3, 4, 5 and 6 report on effects of eccentric and concentric exercise on some parameters of muscle oxygenation and myoelectric activity. Chapter 7 presents a general discussion and conclusion on the studies presented in this dissertation. Chapters 3, 4, 5 and 6 have the references provided at the end of each chapter. These chapters are presented according to the format required by the journals to which they were submitted, that is Applied Physiology Nutrition and Metabolism (Chapter 3; in review), Journal of Sport Science and Medicine (Chapter 4; published), Clinical Physiology and Functional Imaging (Chapter 5; published) and Isokinetics and Exercise Science (Chapter 6; published). Ethics approval was gained from the Human Research Ethics Committee of the University of Sydney for all studies prior to data collection.