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KNEE FUNCTION AND NEUROMUSCULAR ADAPTATIONS FOLLOWING ACL RUPTURE AND RECONSTRUCTION

A thesis submitted in fulfilment of the
requirements for the award for the degree

Doctor of Philosophy

from

University of Wollongong

by

Adam L. Bryant
BHMS (Hons) University of New England, Northern Rivers

School of Health Sciences
2007

CERTIFICATION

I, Adam L. Bryant, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Health Sciences, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Adam L. Bryant

April 2007

DEDICATION

FOR

NATHAN

MY BROTHER & FRIEND…MY INSPIRATION

"He who dwells in the shelter of the Most High

will rest in the shadow of the Almighty"

(Psalm 91:1)

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- Above all, I express my deepest gratitude to God; His love and faithfulness never cease to amaze me.

PUBLICATIONS

The following publications in conference proceedings have arisen directly from the work conducted for this thesis.

Bryant, A.L., Newton, R.U., Bronks, R., & Randle, R. (2000). *Isokinetic torque generated by the quadricep muscles at increasing knee joint angles following anterior cruciate ligament reconstruction: A comparison between patella and hamstring tendon grafts*. Paper presented at the International Congress on Sport Science and Sports Medicine and Physical Education (Pre-Olympic Congress) Brisbane, Australia.

Bryant, A.L., Newton, R.U., Bronks, R., & Randle, R. (2000). *Antagonist activity of the hamstring musculature during knee extension with anterior cruciate ligament deficiency*. Paper presented at the International Congress on Sport Science and Sports Medicine and Physical Education (Pre-Olympic Congress) Brisbane, Australia.

Bryant, A.L., Newton, R.U., Bronks, R., & Randle, R. (2002). *The effects of chronic anterior cruciate ligament deficiency on ground reaction forces, tibial acceleration and length changes of the hamstring muscles during landing and deceleration from a single-legged long hop*. Paper presented at the Australian Conference of Science and Medicine in Sport Melbourne, Australia.

Bryant, A.L., Newton, R.U., Bronks, R., & Randle, R. (2002). *Isokinetic torque generated by the hamstring muscles at increasing knee joint flexion angles following anterior cruciate ligament rupture and reconstruction using either the patella or hamstring tendon grafts*. Paper presented at the Australian Conference of Science and Medicine in Sport Melbourne, Australia.

Bryant, A.L., Newton, R.U., Bronks, R., & Randle, R. (2002). *Activation of the quadriceps and hamstrings during isokinetic knee extension with ACL deficiency and following ACL reconstruction using either the patella or hamstring tendon grafts*. Paper presented at the Australian Conference of Science and Medicine in Sport Melbourne, Australia.

Bryant, A.L., Newton, R.U., & Steele, J.R. (2003). *Knee pain, swelling and giving way: Are these symptoms influenced by ACL reconstruction?* Paper presented at the Australian Conference of Science and Medicine in Sport Canberra, Australia.

Bryant, A.L., Newton, R.U., & Steele, J.R. (2003). *Is tibial acceleration related to knee functionality of ACL deficient and ACL reconstructed patients?* Paper presented at the Australian Conference of Science and Medicine in Sport Canberra, Australia (***British Journal of Sports Medicine Award: Best Clinical Sports Medicine Paper***).

Bryant, A.L., Newton, R.U., Hohmann, E., & Steele, J.R. (2005). *Can we predict knee functionality of ACL deficient and ACL reconstructed patients using tibial acceleration profiles?* Paper presented at the 1st World Congress on Sports Injury Prevention, Oslo, Norway.

Bryant, A.L., Newton, R.U., & Steele, J.R. (2005). *What is the association between knee functionality and hamstring antagonist activation in ACL deficient and ACL reconstructed patients?* Paper presented at the Australian Conference of Science and Medicine in Sport Melbourne, VIC, Australia.

Bryant, A.L., Newton, R.U., Hohmann, E., & Steele, J.R. (2006). *Can we predict the knee function of ACL deficient and ACL reconstructed patients using acceleration transients derived from the proximal tibia?* Paper presented at the British Orthopaedic Association Annual Congress, Glasgow, Ireland.

Bryant, A.L., Newton, R.U., Hohmann, E., & Steele, J.R. (2006). *The relationship between hamstring antagonist activation and knee function in ACL deficient and ACL reconstructed patients*. Paper presented at the British Orthopaedic Association Annual Congress, Glasgow, Ireland.

ABSTRACT

In order to alleviate symptoms associated with progressive knee dysfunction and deterioration following anterior cruciate ligament (ACL) injury, patients undergo either conservative non-operative rehabilitative regimens or early reconstructive surgery using the patella tendon (PT) or combined semitendinosus and gracilis tendon (STGT) grafts. Following treatment, ACL deficient (ACLD) and ACL reconstructed (ACLR) patients demonstrate varying levels of knee function with compensatory neuromuscular adaptations thought to be responsible for enhancing the dynamic restraint capabilities in more functional patients. Derivation of the neuromuscular factors that estimate participation restrictions could assist clinicians in developing prognoses and outcome measures for ACLD and ACLR patients. Therefore, the main aim of the present thesis was to identify neuromuscular variables, derived during open and closed kinetic chain tasks, that relate to and predict post ACL injury/ACLR functional outcome.

To achieve this, 10 male ACLD subjects together with 27 matched-males who had undergone ACLR (14 PT graft and 13 STGT graft) and 22 matched-control subjects were recruited. In Experiment 1, the Cincinnati Knee Rating System was used to assess knee symptoms and limitations associated with activities of daily living and sports. Three single-leg tests designed to replicate athletic activities were also implemented. Subjective and objective scores were combined to provide an overall knee function score for each subject. The ACLD group was significantly more symptomatic and limited in activities of daily living and sports and they also demonstrated impaired jump and hop performance. Whilst the PT and STGT subjects rated significantly higher than their ACLD counterparts, their average subjective and overall knee function scores were significantly lower compared to the control group. Importantly, graft selection did not significantly influence average subjective, objective or overall knee function scores.

In Experiment 2, the effect of ACL injury and ACLR on open kinetic chain isokinetic strength of the quadriceps and hamstrings was assessed in 10^{o} intervals through their operational domain. Antagonist activity of the semitendinosus (ST) and biceps femoris (BF) muscles was also determined during knee extension in 10^{o} intervals between 80 and 10^{o} flexion. Conservatively managed subjects demonstrated significant quadriceps and hamstring weakness with involved limb quadriceps strength deficits transferred to the contralateral limb. Harvesting the central one-third of the PT as an

ACL substitute did not inhibit quadriceps strength compared those ACL-insufficient knees in which the extensor mechanism was not used in the reconstruction technique (STGT graft). In contrast, harvesting the flexor mechanism for ACLR caused significant hamstring strength deficits that were not apparent in patients having undergone ACLR using the PT graft. Relatively large amounts of hamstring antagonist activity were evident during knee extension, although ST and BF electromyographic discharge was not influenced by ACL status. Hamstring antagonist activity increased and decreased widely as a function of joint angle with the BF significantly more active than the ST in order to control internal tibial rotation. Kinesthetic joint capsule receptors were thought to be the major source dictating hamstring muscle activity in such a manner that it varied nearly inversely relative to its moment arm.

In Experiment 3, lower limb kinematics, kinetics and neuromuscular responses were assessed in ACLD and ACLR subjects during a closed kinetic chain task known to stress the ACL, namely abrupt deceleration when landing from a single-leg hop for distance. For the ACLD group, no significant alterations were evident in joint kinematic parameters. Biceps femoris of the involved limb of the ACLD group was activated significantly later compared to the non-involved limb, supporting the notion that after ACL injury, sensory feedback may be used to build a new internal model depicting the expected conditions during functional activities. The involved limb of the ACLD and ACLR groups demonstrated a significant reduction in vertical ground reaction force during the support phase of landing compared to the non-involved limb. Whilst the magnitude of peak tibial acceleration was not significantly different between test limbs or subject groups, it took significantly longer for the involved limb of the ACLD and ACLR groups to attain constant tibial motion compared to the non-involved limb. Subjects having undergone ACLR using the PT graft demonstrated a stiff knee strategy during landing and, whilst the STGT group also demonstrated trends towards decreased knee flexion during landing, no significant kinematic adaptations at the hip, knee or ankle were identified. Decreased knee flexion was found to significantly attenuate the mechanical advantage of the involved limb hamstrings of the ACLD, PT and STGT groups. Cumulative changes in involved limb hip and knee kinematics of the ACLD and ACLR subjects meant that the ST and BF muscles were significantly elongated when decelerating to improve dynamic restraint. Importantly, ACLR led to a restoration of normal quadriceps and hamstring electromyographic (EMG) synchrony in

the involved and contralateral limbs and there was no evidence to suggest that the ACLD subjects adopted a pattern of quadriceps-avoidance.

In Experiment 4, the strength of the associations among knee functionality of ACLD and ACLR subjects (Experiment 1) and neuromuscular variables derived from open (Experiment 2) and closed (Experiment 3) kinetic chain movements was determined. Numerous significant moderate to strong correlations were identified with determinants of knee functionality related to the type of ACL treatment and graft selection. Compensatory neuromuscular strategies that enhance function in the ACLD knee included amplified hamstring co-activation, increased hamstring preparatory activity and a greater ability to control tibial motion during dynamic deceleration. Following ACL replacement, the degree of residual strength deficit in the muscle from which the tendon graft was harvested (i.e. quadriceps or hamstrings) become an important prognosticator of knee functionality as did attenuated hamstring co-activation during knee extension within the range utilsed during single-limb deceleration. More functional PT subjects demonstrated enhanced tibial control whilst superior knee functionality in STGT subjects was associated with increased preparatory activity of the quadriceps when landing on the involved limb. Furthermore, by synchronising peak hamstring muscle activity at the time when the ACL graft is most vulnerable to injury, more functional STGT subjects enhanced dynamic restraint by increasing joint compression and posterior tibial drawer. By identifying neuromuscular factors that predict function in ACLD and ACLR subjects, the results of these studies will lead to the development of more specific and effective treatment strategies.

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LIST OF ABREVIATIONS AND NOTATIONS

Abbreviations and notations used in the text of this thesis are defined below. Abbreviations used in tables are defined within the relevant tables. Symbols used in equations are defined below each equation.

Notation	Definition	Notation	Definition
ACL	Anterior cruciate ligament	IC	Initial contact
ACLD	Anterior cruciate ligament deficient/deficiency	IKDC	International Knee Documentation Committee
ACLR	Anterior cruciate ligament reconstruction/reconstructed	Int15	Interval between 20-10^{o} knee flexion
A/C	Alternating current	Int25	Interval between 30-20^{o} knee flexion
A/D	Analog-to-digital	Int35	Interval between 40-30^{o} knee flexion
ATT	Anterior tibial translation	Int45	Interval between 50-40^{o} knee flexion
CNS	Central nervous system	Int55	Interval between 60-50^{o} knee flexion
BF	Biceps femoris	Int65	Interval between 70-60^{o} knee flexion
BF15	Biceps femoris antagonist activity between 20-10^{o} knee flexion	Int75	Interval between 80-70^{o} knee flexion
BF25	Biceps femoris antagonist activity between 30-20^{o} knee flexion	LH	Lateral hamstring
BF35	Biceps femoris antagonist activity between 40-30^{o} knee flexion	MH	Medial hamstring
BF45	Biceps femoris antagonist activity between 50-40^{o} knee flexion	PT	Patella tendon
BF55	Biceps femoris antagonist activity between 60-50^{o} knee flexion	RF	Rectus femoris
BF65	Biceps femoris antagonist activity between 70-60^{o} knee flexion	ROM	Range of motion
BF75	Biceps femoris antagonist activity between 80-70^{o} knee flexion	S	Soleus
EMG	Electromyography	SM	Semimembranosus
EMD	Electromechanical delay	ST	Semitendinosus
Ext15	Extension torque between 20-10^{o} knee flexion	ST15	Semitendinosus antagonist activity between 20-10^{o} knee flexion
Ext25	Extension torque between 30-20^{o} knee flexion	ST25	Semitendinosus antagonist activity between 30-20^{o} knee flexion
Ext35	Extension torque between 40-30^{o} knee flexion	ST35	Semitendinosus antagonist activity between 40-30^{o} knee flexion
Ext45	Extension torque between 50-40^{o} knee flexion	ST45	Semitendinosus antagonist activity between 50-40^{o} knee flexion
F_{Br}	Peak braking ground reaction force	ST55	Semitendinosus antagonist activity between 60-50^{o} knee flexion
f_c	Filter cut-off frequency	ST65	Semitendinosus antagonist activity between 70-60^{o} knee flexion
Flex45	Flexion torque between 40-50^{o} knee flexion	ST75	Semitendinosus antagonist activity between 80-70^{o} knee flexion
Flex55	Flexion torque between 50-60^{o} knee flexion	STGT	Combined semitendinous and gracilis tendon
Flex65	Flexion torque between 60-70^{o} knee flexion	TA	Tibialis anterior
Flex75	Flexion torque between 70-80^{o} knee flexion	TA_0	Zero tibial acceleration
F_{v1}	Peak vertical ground reaction force	TA_p	Peak tibial acceleration
F_{v2}	Peak vertical ground reaction force during stabilisation	VL	Vastus lateralis
G	Gracilis	VM	Vastus medialis
GA	Gastrocnemius	VMO	Vastus medialis oblique
GRF	Ground reaction force		