Motor control after anterior cruciate ligament reconstruction

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Chapter 7

General Discussion

The journey of this dissertation started with an investigation to determine differences during gait between cohorts of patients with ACLD and ACLR.[1] Interestingly, a majority of the patients with ACLD displayed more normal gait patterns in terms of side to side symmetry when compared to an ACLR group. Our findings showed that the return of normal gait may even take more than one year in patients following ACL injury and specifically ACLR. Interestingly, six months after ACLR is usually the time period when patients are allowed to return to sports.[2-4]
This preliminary study instigated a 10 year journey to finish this dissertation that is aimed to determine the most effective rehabilitation strategies in patients following ACLR. As patients after ACLR in whom a patellar tendon autograft was used, showed significant abnormalities in this study, an interest was triggered as to what could explain the nature of aberrant movement patterns during gait after ACLR. Gait analysis as conducted six months after ACLR, demonstrated that a reduced knee range of motion extension and reduced knee extension moment was used by these patients.
Berchuk and co-workers introduced the term quadriceps avoidance.[5] They postulated that patients with ACLD altered their gait by avoiding the anterior displacement of the tibia by reducing the quadriceps activity that is normally present when the knee is near full extension.[5] It could be argued that patients after ACLR also demonstrate the purported quadriceps avoidance gait to protect the knee from excessive anterior translation of the tibia by reducing the amount of extension during stance.

The results in **Chapter 2** however, demonstrate that a quadriceps avoidance gait did not occur in our patients[6] after ACLR which is in agreement with others.[7] Confirming our earlier work, patients after ACLR displayed reduced knee extension range of motion as well as a reduced internal extension moment of the knee.[1] Moreover, neither anterior laxity nor quadriceps strength was related to the abnormal gait patterns. It is important to note that all patients had full passive extension of the knee. However, as a group they did not utilize these degrees of freedom the joint allowed them to.
If the ACLR leg is not symmetrically loaded compared to the uninvolved side during gait, one would expect the same strategy to be present during high loading activities. Jumping is such an activity, and as such various hop tests are advocated in the literature to determine readiness to return to sports after ACLR. These tests have traditionally been conducted in a time dependent scheme after ACLR, usually at six months after surgery, however some use them even as early as four months.[2,8]

In **Chapter 3** it was shown that six months after ACLR, patients jumped with adapted neuromuscular and biomechanical strategies during a single leg hop task. This could potentially lead to increased risk for second injury. It has recently been shown that patients who have had an ACLR, have increased risk to sustain the same injury, mainly on the contralateral side, when compared to non injured subjects.[9] The incidence of second injury has been reported to be 15 times greater than that of control subjects.[9] In other words, an initial ACL injury itself increases risk for second injury. Split by gender, female athletes following ACLR demonstrated 16 times greater rate of recurrent injury than female control subjects.[9] In addition, female athletes were four times more likely to suffer a second ACL injury and six times more likely than male athletes to suffer a contralateral injury.[10] Biomechanical risk factors associated with the second injury are balance deficits, increased valgus movement of the knee, greater asymmetry in internal knee extension moment and a deficit in hip internal rotation moment at the uninvolved side at initial contact.[9] Right now, the general prevailing thought is that increased risk is potentially due to altered movement patterns and poor neuromuscular control.

However the causes of these increased risk factors due to altered movement patterns are not fully understood or reported in the literature. In our journey, moving from the peripheral explanations like quadriceps strength and laxity of the knee, we chose to evaluate the role of proprioception as part of the explanation on the observed movement patterns in **Chapter 4**. In an extensive review of the literature, there were no strong relationships found between proprioception and motor skills like balance and hopping. As such, the role of prioception seems to be overrated.
Valeriani et al. examined the somatosensory-evoked potentials in ACL injured patients before and after surgery.[11] They detected altered somatosensory-evoked potentials in a number of patients and proposed that ACL injury leads to changed ascending afferent pathways that may cause reorganization of the central nervous system (CNS). Recently, ACLD was shown to alter motor activity of the CNS.[12] Such evidence could help to explain clinical symptoms that accompanied the above mentioned altered movement patterns. Another possibility is that patients have ineffective motor learning strategies. The patients after ACLR demonstrated persistent asymmetry during the gait and jump tasks respectively. It has recently been reported that deficits in force generation and absorption during a vertical jump task are not related to time after surgery.[13] If deficits are not effectively addressed in the early stages after ACLR, they may carry over to other, more difficult motor skills later on.
The issues addressed above, indicate that current rehabilitation programs have not been successful in training patients to load both legs in a symmetrical fashion.[14] If the causes of these abnormal movement patterns are known, rehabilitation programs can be developed and implemented to determine if and how these alterations can be normalized or optimized.

In our effort to understand the described differences in movement patterns in Chapter 2 and 3, we conducted the virtual reality study **(Chapter 5).** We wanted to investigate whether patients following ACLR would move in a more natural way when immersed in a life-like virtual reality setting. The changes in attentional focus, from internal to external, had a greater impact in ACLR patients compared to healthy controls. This raises the question as to whether there is an effective coupling between the surgical procedure and the functional outcome in terms of improved or return of normal movement patterns. Motor learning is the process of an individual's ability to acquire motor skills with a relatively permanent change.[15]
It appears that patients after ACLR as studied in Chapter 5 are not fully capable of using the potential of plasticity of motor learning. Effective motor control calls for an efficient information processing between the body, brain and environment (embodied cognition).[16] The motor system has the ability to adapt to environmental constraints and injury to itself. In case of a normal scenario, one would expect that patients after ACLR would fully recover in terms of restoration of normal movement patterns as prior to the injury. Evidence however is emerging that movement patterns may not fully restore after ACLR.[9,13,17-28]

The reasons as to why patients after ACLR may not accomplish normal movement patterns are probably multi-factorial in nature. These factors will be briefly outlined in the following section and a paradigm change in presented.
First, changes in the sensorimotor system need to be considered. It has been shown that an ACL injury causes direct changes in the CNS. Recent studies have shown that altered activity of the motor cortex is present both in ACLD patients as well after ACLR.[11,12,29,30] For example, patients with ACLD who were able to participate in sports despite a ruptured ACL had changes in central sensory representation when compared to patients with ACLD who experience instability of the knee.[31] Based on the aforementioned, a ruptured ACL should be regarded also as a neurophysiological lesion instead of only a simple musculoskeletal lesion.
Secondly, the fear-avoidance model (FAM) may be applied to patients after ACLR. The FAM is a biopsycho-social model proposed to explain the development of chronic disability after musculoskeletal injury.[32] The FAM proposes that when pain is perceived as a threat following musculoskeletal injury, various psychosocial constructs, such as increased pain catastrophizing and fear of movement or reinjury, are altered, leading to disuse, depression, disability, and higher pain levels. Recently, improvements in self-efficacy for rehabilitation tasks and fear of movement or reinjury were shown to be predictors of improvements in knee pain and function.[33]
Third, the paradigm change that is presented is based on the results of Chapter 5

shedding a different light on the results of Chapters 2 and 3. The contention as outlined in this dissertation, is that patients after ACLR may utilize an increased attentional, cognitive focus on movement which inhibits the learning process of regaining normal movements.

During the immediate period after ACLR, the execution of movement requires attention as directed by physical therapists and physicians, so that there exists also a dependency on cognitive control. In earlier research it was postulated that throughout the learning stages, dependency on cognitive and visual control of movement diminish in the final stages of learning in that execution of motor skills become automatic again.[34] Patients after ACLR may fail to advance to the more autonomous phases of motor control, and a result demonstrate altered movement patterns that are governed by too much cognitive control. The postulated causes of altered movement pattern after ACLR need to be more explored in future.

IMPLICATIONS FOR REHABILITATION

As a continuum of these findings, we reviewed literature related to motor learning research. It is common in rehabilitation settings to provide instructions and feedback to facilitate motor skill learning during rehabilitation. Typically, the feedback is directed at the various components of the movement. The treating clinician may tell a patient who has an altered gait pattern after ACLR, to extend the knee more during the stance phase. In motor learning, this type of attentional focus is termed “internal focus” as it induces the performer’s attention directed towards the actual movements produced.[35] Conversely, an external focus of attention is induced when a performer’s attention is directed towards an outcome or the effects of the movement being produced (e.g., “imagine to kick a ball”, to facilitate extension of the knee). Prior reports indicate that 95% of physical therapists provide feedback instructions with such an internal focus.[36] Research is evolving that indicates this type of instructing with this type attentional focus may not be as effective as previously thought.[37] Traditionally, instructions during landing from jumping are directed towards the execution of the movements itself. Often used instructions are “keep the knee over the toe”; “land with a slightly flexed knee”; “raise the knee to the level of the hip” or “land with your feet shoulder-width apart”.[2,38] Although, there are intuitive reasons that clinicians give internally focused instructions, this approach may even foster more difficulty in patients following ACLR to re-learn skills. Such an internal focus results in an increase of co-contraction which in turn may cause “freezing” by limiting the degrees of freedom of movements.[37]

More recently, Wulf and Lewthwaite expanded this explanation by suggesting that the mere mention of the participant's body parts provokes a focus on the patient him-/herself.[39] The self-construct has increasingly been recognized as an important factor within social environments, influencing individuals' thoughts, actions, and behavior, often implicitly.[40] The fact that motor performance often takes place in the presence of others and can be evaluated by them, may in and of itself lead to a state of self-consciousness and subsequent self-evaluation. This, in turn, can lead to "micro-choking" episodes and a switching of attention to self-regulatory activity.[39] Efforts to manage self-related thoughts and emotions may be so demanding that available attentional capacity is exceeded and performance suffers. It is also conceivable that these processes promote a conscious control of both movement and self-regulatory activities.[41] Considering that feedback, by its nature, implies an evaluation of an individual's performance, it may not be surprising that frequent feedback can have detrimental effects compared to less frequent feedback.[42] These effects are most likely exacerbated when individuals are provided with specific body-related or internal-focus feedback. In contrast, the "self-invoking trigger" does not come into play when the feedback promotes an external focus.[35,43,44]

In fact, frequent external-focus feedback seems to serve as a potent reminder to maintain beneficial effects on performance and learning.[45]

Of interest, in most rehabilitation situations, clinicians determine the details of the training session. They decide, for example, on the order of practice tasks, practice duration, and when or if feedback will be provided or demonstrations given. Thus, whereas clinicians generally control most aspects of practice, patients assume a relatively passive role. Yet there is converging evidence that the effectiveness of skill learning can be enhanced if the patient is given some control over the practice conditions. That is, a certain degree of self-control can result in more effective learning than completely prescribed training protocols.[46,47] Finally, motor learning seems to be enhanced by positive relative to negative normative feedback.[48,49] Negative normative feedback on the other hand may hamper motor learning. This finding of impaired learning with indications of poor performance is in line with the findings of several recent studies which demonstrated that feedback provided after "poor" trials is not as effective for learning as feedback provided after "good" trials[50] and that negative normative feedback degrades learning relative to positive social-comparative feedback.[39,51] Empirically, clinicians often provide feedback in terms of correcting the patient's faulty performance of a given task.[2] However, beliefs about personal capability have been shown to affect performance. The results of aforementioned studies also highlight the role of motivational influences on motor learning.[52] In summary, it is worthwhile to give patients positive remarks to enhance learning.

FUTURE DIRECTIONS

Although this dissertation can only answer a small percentage of all variables involved in aberrant movement patterns, several interesting findings were revealed that may change rehabilitation programs following ACLR. Most athletes who wish to continue sports after an injury to the ACL are advised to undergo surgical reconstruction of the ligament.[3] Nevertheless, reconstruction of the ACL does not equate to normal function of the knee or reduced risk of subsequent injuries. Injury rates for a second injury exceed 20% for young highly active athletes returning to sports within the first year after surgery.[9] In Sweden, 22% of the 15- to 18-year-old female soccer players reported a revision or contralateral ACLR during a 5-year period.[53] Recently, it was shown that return to a high activity level after a unilateral ACLR was the most important risk factor of sustaining a contralateral ACL injury.[54]

There is a plethora of data available that indicates that biomechanics are altered after ACLR that persist for several years and likely increase risk for injury to the contralateral side.[9] Given this outcome, it appears that current rehabilitation programs may not provide effective stimuli to patients after ACLR to improve their altered movement patterns and prevent secondary injury.[14]
Novel training methods may target asymmetrical movement patterns in patients following ACLR during activities that may pose athletes at risk for re-injury. Insight gained from recent motor learning research and current dissertation may improve the effectiveness of secondary prevention of ACL injury and outcome in terms of returning to pre-injury athletic levels. The effect of factors like external focus, self-controlled learning and positive feedback should be investigated in rehabilitation after ACLR. Ideally, future rehabilitation employing principles from motor learning could be implemented to successfully target increased risk of second injury and reduce or delay the onset of osteoarthritis.

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