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## Prevention of non-contact ACL injuries in Women: Use of the Core of Evidence to Clip the Wings of a “Black Swan”

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### INTRODUCTION

#### An Exploration of the Clinical Enigma

A high school forward rebounds the basketball as she has thousands of times before. She lands with a flat foot, extended knee, and torso leaning awkwardly sideways, as her knee buckles inward. An audible pop is heard and felt as the Anterior Cruciate Ligament (ACL) in her knee tears and ends her season, compromises her hopes of a college scholarship, and perhaps even her expectation of a long, active, and healthy life. My M.D./Ph.D. student Carmen, who began working in my laboratory after both she and her identical twin sister both suffered devastating non-contact ACL injuries while playing high school sports, recently gave me the gift of an irreverent treatise titled “The Black swan: The Impact of the Highly Improbable.” Written by self-assured and self-described “empirical skeptic,” Nassim Nicolas Taleb, the running theme of the book is a zealous critique of our ability to predict unexpected events which he refers to as “black swans.” By Taleb’s definition of a “black swan,” which is an event that is rare, has a major impact, and one that we teleologically ascribe the obvious reasons for it happening, but only after it has already occurred. She gave me the book because it “reminded her of me!” As an empirical skeptic of sorts myself, I was only a page or two into the prologue, when I realized that a non-contact ACL injury is, by Taleb’s definition, a “Black swan.”

#### The Underlying Mechanisms

The underlying mechanisms of non-contact anterior cruciate ligament (ACL) have yet to be precisely defined; however, we now have a relatively good understanding of the mechanisms and interventions to prevent these injuries. Though I agree with Taleb that chaotic events are difficult, if not impossible, to predict, most of the available evidence indicates that prophylactic interventions that target underlying mechanisms of ACL injuries can decrease risk. Theories for the underlying mechanisms of these injuries may be divided into intrinsic and extrinsic mechanisms. Extrinsic factors include variables such as playing surface, shoe type, and number of risk exposures. Intrinsic mechanisms include anatomical, hormonal, and most importantly, neuromuscular factors. Neuromuscular mechanisms should be emphasized because they are the intrinsic factors that appear to have the greatest effect and the only ones we can readily alter. Anatomic variables include increased Q (quadriceps)-angles or decreased notch width, which may strain or impinge the ACL. Hormonal theories propose that estrogen increases

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ligamentous laxity of the ACL predisposing it to injury. Systematic reviews of the literature show that though there is a slight, increase in ACL laxity during the *post*-ovulatory phase of the menstrual cycle, but the injury events show significant clumping during the *pre*-ovulatory phase of the cycle! Hence, these “predictive” factors are as chaotic (and contradictory) as the injury occurrences themselves! It is too much to expect of naive scientists to discover the contributions of such complex hormonal feedback and feed-forward systems on such an acute injury event. Finally, a multitude of studies show neuromuscular control differences between women and men. However, a major *caveat* to these studies is that IF a measurable variable is observed to be different between the sexes, we cannot conclude THEN that this difference must underlie the injury risk disparity between the sexes. We need to remember, men experience many ACL injuries, too.

Despite intensive study of ACL injuries during the past three decades, previous reports on actual ACL injuries were based on interviews with the athletes or descriptive analyses of videotapes. These sources are not ideal for analysis because athlete interviews are highly subjective and prone to inaccuracies secondary to trying to recall the details of an extremely rapid (<100 msec), painful, chaotic event that occurred some time in the past. Our laboratory has employed what we think is a paradigm-shift in the field of sports medicine, what we term prospective, longitudinal, coupled biomechanical-epidemiologic studies that are geographically-based (entire County school systems) to address this important problem and to answer very specific study hypotheses. To our knowledge, these state-of-the-art, labor-intensive tools of investigation have not been used previously to investigate such questions. In addition, we currently use computer modeling to compliment these biomechanical studies and to simulate what occurs during the injury event and identify the high risk athlete. We hope to be able to tailor neuromuscular intervention strategies to the athlete’s specific neuromuscular control deficits.

### The Sex Disparity

I grew up the sole boy among six active, older sisters. I always had a good idea of the potential power of women’s sports. My sister Patti was the best athlete in our neighborhood and went on to play multiple collegiate sports. However, because she grew up in the sixties, she missed out on the immense influence and power Title IX has had on the young women of later generations. My sister Jenny tore her ACL playing basketball and now suffers from a debilitating, unstable and osteoarthritic knee. Many of the young women these days are not only great athletes, but their entire social network is tied up in their sport. Consequently, loss of participation can be a devastating effect of the injury. We know from the long-term data coming out of Scandinavia that 50% to 100% of women with ACL tears, whether they have the ligament reconstructed or not, will go on to osteoarthritis within one to two decades of the original insult.

Serendipity may be defined as “a fortunate accident.” I have experienced it a few times in my scientific life, and it has become one of the few concepts that this empirical skeptic greatly values (especially if it comes in the form of valid scientific discovery). One such serendipitous scientific discovery for me came while we performed a high school outreach study in the early nineties. Designed to test the effects of plyometric neuromuscular training on performance in female high school athletes, we made the important discovery that these athletes demonstrate specific neuromuscular imbalances, that not only differentiate them from males, but that also correlated to observed ACL injury mechanisms. For the past two decades, we have used our prospective coupled biomechanical-epidemiologic approaches to determine that these neuromuscular imbalances indeed likely underlie the increased risk of non-contact ACL injury.

### **Neuromuscular Imbalances Associated with the Underlying Mechanisms**

More recently, another promising line of inquiry looking at the influence of the trunk on ACL injuries was the result of a serendipitous conversation I had with a group of spine biomechanists at Yale. Examination of their data from a series of studies originally designed to examine risk factors for future onset of low back pain, we reanalyzed the data relative to subsequent knee injury events, and discovered that collegiate women athletes who do not sense or control their trunk (or “core” position) well in 3-dimensional space, had significantly higher risk of future knee and ACL injury. Interestingly, men showed no such association between “core control” and knee and ACL injury risk. I value these finding highly since there was no inherent bias to the study design or the hypotheses. The spine biomechanists who set up the study to examine low back pain had no *a priori* intention to examine the parameters of core control relative to knee injury risk.

### **Growth and Development Exacerbates the Neuromuscular Imbalances**

Our current theory is that pubertal growth in the absence of a neuromuscular spurt, results in neuromuscular imbalances that directly underlie the ACL injury mechanism. These observed neuromuscular imbalances give important clues for guiding prevention program strategies. The dynamic neuromuscular imbalances commonly observed in females can be divided into several broad categories. The first imbalance is the tendency for females to be ligament dominant. Ligament dominance refers to the absence of muscle control of medial-lateral knee motion that results in high valgus knee torques and high ground reaction forces. A second common imbalance is referred to as “quadriceps dominance.” Athletes with quadriceps dominance preferentially activate their knee extensors over their knee flexors and gluteal muscle groups to stabilize their knee during movement. This imbalance accentuates and perpetuates strength and recruitment imbalances between these muscles. Yet another imbalance is leg dominance. This imbalance is characterized by one leg with weaker and less coordinated hamstrings musculature than the other. A final observed imbalance can be termed “trunk dominance,” in which the momentum of the trunk is not controlled sufficiently, which leads to uncontrolled motion of the center of mass during deceleration and movement of the ground reaction force vector to the lateral side of the joint.

### **Correction of the Neuromuscular Imbalances to Correct the Problem**

Neuromuscular imbalances can be used as screening tools to identify athletes at increased risk and funnel them into efficacious neuromuscular training programs that target each athlete’s specific neuromuscular imbalances. A potential “black swan” ACL injury event may transform into a “gray swan” once we identify an athlete at risk. This athlete is now “inside our radar screen,” since we now know that they are at risk and we have targeted them for intervention. Taleb claims that we should abandon attempts at predicting “black swans” but “gray swans” are potentially predictable and even preventable.

The correction of neuromuscular imbalances is an important concept for the development of any neuromuscular training program. Neuromuscular balance is important in every plane of motion (*i.e.*, imbalance of neuromuscular parameters usually occur in all three muscular contraction planes). ACL injury is a multi-planar injury and the sports movements that cause them likely occur in all three planes of motion. Ligament dominance can be addressed with awareness training and biomechanical technique and biofeedback training. Quadriceps dominance imbalance can be addressed with plyometric power training in flexion positions. Leg dominance imbalance can be addressed with single leg balance and symmetry training. Trunk dominance can be addressed with core stability training. Multiple randomized controlled trials have demonstrated that Neuromuscular training programs focused on neuromuscular reeducation of these imbalances are highly effective in increasing control of dynamic movement and decreasing ACL injury both in the laboratory and on the playing field. A Black

Swan like an ACL injury is a random and chaotic event that occurs in all three planes of motion. Therefore, it is likely that we cannot predict a single occurrence of a non-contact ACL injury. However, it does appear that we can likely predict a profile of increased risk. In addition, we may be able to predict risk for and develop neuromuscular interventions to prevent 2<sup>nd</sup> injury which occur at an extremely high rate (12% to 28%) in the young active female population.

### **Future Directions: What do we do next?**

So what are our next steps in the decipherment of this hidden, chaotic and destructive process? First, the new interventions to be tested must target all planes of motion. Our future study designs must be rigorous; we must employ randomized, controlled trials (RCT), with placebo treatments in place. We must have sham treatments in place to control for bias, confounding, unnecessary error, and incorrect interpretation of results. Moreover, result interpretation may be the most common and greatest offender, as Taleb warns us in “Black swan,” bias is inherent to the human mind, and must be avoided in our intervention efforts at all cost.

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