

APPLICABILITY OF OPERATIONS RESEARCH AND ARTIFICIAL INTELLIGENCE APPROACHES TO NON- CONTACT ANTERIOR CRUCIATE LIGAMENT INJURY STUDIES

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Numerous problems in biomechanics can be tackled using optimization methods. The primary objective of this paper is to explore the applicability and illustrate the importance of two major optimization approaches, namely, operation research (OR) and artificial intelligence (AI) to studies in non-contact anterior cruciate ligament (ACL) injury biomechanics. This paper focuses on the applicability of the two approaches to bring attention to the enabling capabilities that can be offered to address challenges faced in non-contact ACL injury studies. The differences and similarities, as well as, advantages and disadvantages of these two approaches are discussed. Some of the key techniques covered in the two different approaches are highlighted. As well, the area in which there is a common ground for both approaches is outlined. It was determined for a small search space and highly tailored problems, classical exhaustive OR methods usually suffice; however, for large search spaces an AI technique must be employed. Thus, an AI technique is better suited to tackle the challenges faced in non-contact ACL injury studies especially given the multifaceted nature of such problems.

KEY WORDS: ACL injury, optimisation, operations research, artificial intelligence

INTRODUCTION: Operations research (OR) is concerned with the quantitative specifications of problems and the use of mathematical techniques to solve these problems. Artificial intelligence (AI) is concerned with making computers capable of emulating intelligent behaviour (Holsapple, Jacob et al. 1994). Since the ability to solve problems is one of the hallmarks of human intelligence, a major AI focus is on computer-based techniques for solving problems (Carter and Price 2001). Historically, OR and AI research communities worked in relative isolation from one another. This separation is difficult to understand, since both disciplines share many similarities deeply concerned with questions of human problem solving and decision-making. In addition, both approaches are highly computer dependent, share a common conceptual framework, and require methods that effectively cope with uncertainty and imprecision (Kanal, Lemmer et al. 1987; Pearl 1988). Despite these similarities both approaches are highly distinct from each other. For instance, AI has a strong foundation in logic with methods that emphasizes automatic theorem proving, while OR puts emphasis on the mathematics of optimization (Holsapple, Jacob et al. 1994). In addition, OR has been found useful for decision-making, while AI pursuit deals in automatic decision-making. As well, OR focuses on the management of procedural knowledge, while AI tends to focus on the management of reasoning knowledge. There are few studies on the applications of AI and OR techniques to improve our understanding of non-contact injury to the ACL. To study ACL mechanics classical optimization techniques such as the Newton-Raphson search method or mathematical programming cannot be employed because of the absence of a polynomial type function. More importantly, these techniques cannot handle many design parameters in a large domain. Monte Carlo and mathematical programming method are the dominant OR techniques used in the literature to investigate non-contact ACL injury (Blankevoort and Huiskes 1996; McLean, Su et al. 2004). These two techniques are used primarily in applications to evaluate the probability of random outcomes of human movement (McLean, Su et al. 2004) and to solve a series of

mathematical equations (Abdel-Rahman and Hefzy 1993; Blankevoort and Huiskes 1996) respectively. Monte Carlo simulation is an attractive tool since it allows researchers to study and predict risk of sustaining an injury before injury occurs. Non-contact ACL injuries typically occur when several extreme conditions or risk factors happen at the same time. Monte Carlo simulation can estimate the probability when multiple extreme conditions are satisfied, which then allows one to predict the risk of injury. Nonetheless, Monte-Carlo methods are algorithms that randomly generate and retain the best solutions before going to the next search iteration. Rather than presenting an historical review of what has been done, this paper takes a more explicit approach, discussing the work in three fields: 1) overview of AI and OR approaches; 2) present challenges in non-contact ACL injury studies; and 3) application of AI and OR to enable us to address some of these challenges encountered in non-contact ACL injury studies.

METHODS: This article reviewed the relevant literature on non-contact ACL injury mechanisms, OR and AI optimization techniques in the PubMed electronic database using MEDLINE (1966 to 2007) and Applied and Complementary Medicine Database (AMED) on Ovid (1985 to Sept. 2007). Unpublished data and abstracts were excluded. Our search was supplemented by reviewing the bibliographies of retrieved articles as well as hand searching scholarly journals.

RESULTS: Overview of Optimization: Any problem in which design parameters have to be determined, (assuming such parameters exist), given certain constraints, can be treated as an optimization problem (Carter and Price 2001). Typically optimization methods seek to improve rather than create new ideas. However, the ability of optimization methods to mold new ideas should not be ruled out, since optimized solutions usually lead to new designs that are in some cases unique.

Operations Research (OR) Perspective: From an OR perspective there are specific problems and explicit procedures for solving such problems. It is the wording or problem statement that helps us to decide which OR method to use. Hence, a given procedure requires a certain type of problem statement as a precondition for execution. This has somewhat made OR procedures unattractive for solving complex problems. Mathematical programming appears to be the cornerstone of OR techniques and is arguably the most widely used and visible extension of the field. To gain a more thorough understanding of OR, available OR techniques, as well as, details on coding ones own technique, please consult (Winston 1994).

An Artificial Intelligent (AI) Perspective: For many practical problems encountered, the only way to be sure of finding an optimal solution is to search completely through the whole set of possible solutions. The time required to carry out such an exhaustive search is, although finite, far greater than most institutions can afford. The pretext then is to find shortcuts that will allow one to organize the search process so that it is no longer a complete search over all possible solutions, but rather it becomes an affordable search that is likely to find optimal or near optimal solutions. These methods are called artificial intelligent, heuristic or soft computing techniques. To gain a more thorough understanding of AI, available AI techniques, as well as, details on coding ones own technique, please consult (Pham and Karaboga 2000).

Present Challenges in Understanding non-contact ACL Injury: There has been much interest in quantifying the ACL loading *in vivo* during activity (Beynon, Fleming et al. 1995). This is motivated by the high incidence of ACL injury, lack of understanding of ligament mechanics, and frequent requirements for surgical treatment. Despite the advances in research to understand knee mechanics, little is known about the mechanism of ACL injuries. There is also no clear consensus that implicated factors for non-contact ACL injury are indeed risk factors.

Presently, *in vitro* investigations using cadavers dominate in the arena of ACL injury mechanics. Here the ACL is initially studied when intact, after the ACL is sectioned, and finally after the ACL is reconstructed. *In vitro* studies have provided tremendous knowledge on the function of the ACL, but they do not appreciably help us increase our insight and understanding on the mechanism of ACL injury.

The vast majority of studies do not address the effects of hip and ankle kinematics on ACL loads. Torso, hip, and foot motions were suggested to modulate 3 of the 4 quadriceps muscles, the gastrocnemius, and the hamstrings via their length tension relationship, which has been shown to affect risk of ACL injury (Withrow, Huston et al. 2006). In addition, the vast majority of the studies in the literature do not account for the effects of whole body movement on ACL loads, despite its distinct effect (Peña, Calvo et al. 2007).

Other overarching challenges in non-contact ACL injury studies include the difficulty entailed when comparing results from one study to another due to the tremendous heterogeneity between studies. As well, there is large variability in biological tissues material properties reported in the literature. In addition, extracting soft tissue three dimensional (3D) geometries remains a challenge, especially for those that are intra-articular like the ACL.

AI and OR Applied to Non-contact ACL Injury Studies: Numerous real-world problems entail the fusion of many disciplines. This is due to the recognition that the design and development of complex systems can no longer be done in subsections with each discipline isolated from each other. The needed for a more comprehensive strategy is imperative given the increase level of complexity within disciplines, and the need to extract the advantages of a synergistic design process (Hajela 1999). Multidisciplinary design optimization (MDO) has recently emerged as a field of research and practice that brings together many previously disjointed disciplines and tools of engineering. Typically MDO involves many design variables, many constraints, and analysis from various contributing disciplines that are not independent.

Many studies utilizing optimization in biomechanics have been concentrated in the orthopedics arena (Yoon and Mansour 1982). AI techniques have received tremendous attention over the years compared to OR techniques primarily because they do not require gradient information, they are more robust in handling both continuous and discrete design variables, and above all, they share an enhanced ability to locate the global optimal solution.

Clinical studies, interviews with athletes, and video analyses are non-contact ACL injury study approaches that provide mostly qualitative data, and as such, they are not well suited for obtaining a clear and comprehensive understanding ACL injury mechanism. On the other hand, computational modeling, musculoskeletal modeling, and experimentation are quantitative ACL injury study approaches that all have their own advantages and disadvantages. The authors' view is that the seamless integration of all three quantitative methods, i.e. computational modeling; musculoskeletal modeling; and experimentation, is a more robust study approach to better predict non-contact ACL injuries. In this approach the three qualitative approaches, i.e. clinical studies; interviews with athletes; and video analyses, can be used to aid validation. More importantly, an AI technique is employed to combine all six study approaches, as well as, to facilitate search and optimization. This type of study approach process is absent from the literature. The author's believe this method can enable us to simultaneously determine knee kinematics and kinetics, muscle activation and loading patterns, joint compressive stresses, and ground reaction forces (GRF) at which the ACL is at high risk of injury. To elucidate, one possible approach is a 3D musculoskeletal-driven finite element model of the lower extremity that is verified and validated with experiment, clinical studies, interviews with athletes, and video analysis studies. In this approach to address the numerous variables and constraints involved, the immense variability in material properties, uncertainty and unknowns such as inciting position of ACL

injury, a genetic algorithm can be utilized. The genetic algorithm also functions to tie all disciplines together thereby facilitating an automatic or semi-automatic transfer of data.

Key Findings: It was determined that application of AI and OR approaches to research centered on non-contact ACL mechanics is primarily limited to OR techniques. A possible study approach that can enable researchers to overcome some of the challenges faced in non-contact ACL mechanics studies was presented. It was emphasized that despite scarcity of AI application to ACL injury mechanics studies, AI is very much well suited for addressing many of the limitations of existing ACL mechanics study approaches. This can provide opportunities to researchers in this field to take benefit of powerful AI techniques.

CONCLUSIONS: A brief overview of optimization was presented. The two main areas of optimization namely operations research and artificial intelligence were discussed in the context of its application to study non-contact ACL injury. Some of the key gaps in knowledge in the literature pertaining to non-contact ACL injury studies were also presented. Finally, the capabilities of AI and OR techniques were covered, and recommendations put forth on how existing non-contact ACL injury study approaches can be united with an AI technique to reinforce our understanding of ACL mechanics. Even though OR techniques applied to study biomechanics problems is prevalent they lack the robustness required to investigate complex problems such as non-contact ACL injury. So the nature and complexity around non-contact ACL injury requires an AI approach.

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