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by Sanaul Haque

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AI-Assisted Prediction Models for Primary Anterior Cruciate Ligament Injury Risk and Recovery Time Using Basketball Athlete Performance Data

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Research Aims: This research project aims to analyze the injury risk and recovery time associated with primary Anterior Cruciate Ligament (ACL) injuries, particularly among basketball athletes. The main objectives of this study are as follows: 1) To improve the accuracy of ACL injury risk stratification through Artificial Intelligence (AI), 2) To identify the most contributing risk factors for ACL injury, 3) To provide a reproducible framework for injury risk prediction that can be adapted in clinical and sports performance settings, 4) To improve the accuracy of ACL recovery time prediction models through AI, 5) To identify the most contributing factors to ACL recovery time, and 6) To provide a reproducible framework for recovery time prediction that can be adapted in clinical and sports performance settings.

Research Questions:

Central Question:

How can AI-assisted machine learning models predict ACL injury risk and recovery time in basketball athletes using performance and clinical data, while accounting for differences in gender and rehabilitation programs?

Sub-Questions:

1. How can ACL injury risk be assessed using pre-injury performance data?
2. How can ACL recovery time be estimated using patient-specific metrics and surgical history?
3. Which machine learning models achieve the highest predictive accuracy and reliability in predicting ACL injury risk and recovery time?
4. Which rehabilitation programs are the most effective for minimizing return-to-sport time in athletes after ACL injury?
5. Do male and female athletes differ in ACL injury risk, and which gender demonstrates a higher injury rate?

Introduction:

Background of the Issue: Anterior Cruciate Ligament (ACL) injuries are among the most prevalent and debilitating musculoskeletal injuries, particularly affecting basketball athletes and physically active individuals. The ACL plays a crucial role in maintaining knee stability by limiting anterior tibial translation and rotational forces. When injured, athletes often experience functional instability, prolonged rehabilitation, and an increased risk of osteoarthritis later in life.

Current Scope of Research: Traditionally, clinicians have relied on factors such as demographic characteristics, a history of prior injuries, and biomechanical evaluations to estimate the risk of injury. However, these methods can be limited in predictive accuracy and may not fully capture the complex interplay of factors that contribute to ACL injuries. Recent advances in data analysis and machine learning have opened new opportunities to improve risk prediction by leveraging large data sets that include demographic, biomechanical, and clinical variables.

Importance of Research: Identifying athletes who are at increased risk for ACL injury is a critical step toward developing targeted prevention strategies and improving clinical outcomes. Machine learning models such as Random Forests, Gradient Boosting, Logistic Regression, and Linear Regression can discern complex nonlinear patterns to classify injury risk with higher accuracy, provide insight into which variables most strongly influence model predictions, and offer valuable guidance for targeted intervention programs.

Gaps in Research: Existing studies rely too heavily on systematic reviews, which lack data analysis, machine learning, and artificial intelligence (AI). Furthermore, they focus on neuromuscular and anatomical factors, but underestimate training data, such as training hours and intensity. Finally, current studies lack research on primary ACL injuries, prediction models for recovery time, and interpretable approaches, such as Random Forest. Therefore, this novel research project will address all these research gaps by developing AI-assisted machine learning prediction models and using Python-assisted data analysis to analyze and predict the risk of primary ACL injury and recovery time.

Literature Review:

ACL Re-Injuries: Many existing studies have evaluated the risk factors that contribute to ACL injuries. For example, Hewett et al. [1] analyzed the importance of biomechanical and anatomical screening through a systematic review, while Paterno et al.'s cohort study [2] found that athletes who had ACL reconstruction (ACLR) were 6 times more at risk compared to healthy athletes. Furthermore, Wiggins et al. conducted a systematic review and meta-analysis [3] to evaluate the primary risk factors for ACL re-injury, and the 2-year cohort study by Grindem et al. [4] used quadriceps strength tests to find out that an early return to high-risk sports increases the chances of ACL re-injury. Others, like Hunnicut et al. [5], relied on observational studies to conclude that patients after ACLR were significantly weaker in quadriceps strength. Finally, researchers like Girdwood et al. [6] evaluated the deficits in quadriceps strength after ACLR through a systematic review. Existing studies underestimate the risk of first-time ACL injury, as they primarily investigate reinjuries. They rely too heavily on systematic reviews and cohort studies and underestimate real-world training data, since they mostly assess neuromuscular and anatomical factors.

Systematic Reviews and Meta-Analyses: Existing studies such as Niederer et al. [7] and Ardern et al. [8] focus on the importance of recovery from ACL injuries through systematic

reviews and meta-analyses. These studies found that the delay between injury and surgery was detrimental and that younger athletes were more likely to return to competitive sports. Spindler et al.'s therapeutic study [9] evaluated knee-related quality of life in patients, while McGrath et al.'s case study [10] discovered that functional performance tests are reliable predictors of safe return to play (RTP) in 64 patients. Furthermore, water rehabilitation (WR) training was shown to have a superior efficacy than total body vibration training (WBVT) through the meta-analysis by Zhong et al. [11]. Finally, a systematic review by Hogber et al. [12] reviewed whether knee flexor strength is associated with a second ACL injury. The existing literature uses recovery time as a factor that contributes to the recovery outcome, instead of identifying the factors that contribute to recovery time. Systematic reviews and meta-analyses are also overused and lack machine learning prediction models and artificial intelligence (AI).

AI and Machine Learning: Machine learning models have been used to predict sports-related recovery using clinical data. For example, the retrospective cohort study by Chu et al. [13] concluded that machine learning models can accurately predict prolonged concussion recovery in young athletes, but did not address ACL injuries. A systematic review by Corban et al. [14] found that there is an increasing interest in AI among orthopedic surgeons, but many challenges still need to be addressed. Furthermore, Schulc et al.'s laboratory study [15] identified biomechanical patterns in ACL injuries through an automated video analysis system. These studies lack advanced machine learning models and interpretable approaches. Clinicians like Bonci et al. [16] and Beynnon et al. [17] have used many ways to estimate the risk of ACL injury. These studies relied on narrative overviews and cohort studies to evaluate static postural malalignments, knee recurvatum, and risk factors for non-contact injuries in college and high school students. Furthermore, researchers such as Paterno et al. [18] use case-control studies to evaluate whether standard clinical measures predicted the risk of second ACL injuries.

Summary: In general, literature reviews and cohort studies can be limited in predictive precision, unlike machine learning models that can improve injury risk prediction and offer valuable guidance for targeted intervention programs. Clinical predictions undermine the importance of ACL recovery time. Therefore, this novel research project will bridge these gaps by using advanced data analysis and machine learning tools to build AI-assisted prediction models for the risk and recovery time of primary ACL injury using data from basketball players.

Research Methodologies:

The methods for this research project will involve data collection and analysis, Python plotting, and machine learning for AI-assisted predictions.

Data Collection: Data will be collected from two ACL injury data sets (Athlete Injury and Performance Dataset & Basketball Player Injury in Sports Rehabilitation) to provide information on factors associated with the risk of ACL injury and recovery time for basketball athletes. The first data set will capture the demographics of athletes and training regimes, while the second data set will capture biomechanical metrics and rehabilitation outcomes.

Data Analysis and Python Plotting: Pivot tables will be generated to provide insights, while Python plotting will be used to create plots, such as line graphs, bar graphs, and pie charts, that represent the results. The data factors that will be analyzed for ACL injury risk are age, sex,

height, weight, training intensity, training hours, and rest days. Furthermore, the data factors that will be evaluated for ACL recovery time are age, height, weight, jump height, speed, and rehabilitation efficiency. To analyze injury risk, data will be collected from 200 different college basketball players, and injury rates will be calculated based on 14 athletes who suffered an ACL injury. Moreover, to evaluate recovery time, data will be collected from 100 different basketball athletes with injuries, and injury rates will be calculated based on 21 athletes who had an ACL tear.

Machine Learning Models: Using these data and insights, machine learning models such as Random Forest and Gradient Boosting will be trained and tested to see which ones were the most accurate when it comes to predicting the risk of ACL injury and recovery time. Random Forest and Logistic Regression will calculate the accuracy, precision, recall, and ROC-AUC for injury risk classification. Random Forest, Gradient Boosting, and Linear Regression will calculate RMSE, MAE, and R2 for recovery time prediction.

Conclusion:

This research, in short, tackles the unending problem of ACL injuries, which has been one of the most devastating sports injuries for athletes competing in high-intensity sports like basketball. In the past, many clinicians and researchers had tried to predict the risk of injury, but were limited in predictive accuracy, as recent advances in machine learning have opened new opportunities to improve risk prediction. This study strongly indicates the necessity of targeted prevention programs to reduce the risk of ACL injury for basketball athletes. As AI and machine learning continue to develop, they can improve the accuracy of scientific predictions. Therefore, future studies should investigate the efficacy of AI-assisted prediction models and specific exercises in prevention programs.

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