Prevention and Screening Programs for Anterior Cruciate Ligament Injuries in Young Athletes

A Cost-Effectiveness Analysis

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Background: Anterior cruciate ligament (ACL) injuries are common among young athletes. Biomechanical studies have led to the development of training programs to improve neuromuscular control and reduce ACL injury rates as well as screening tools to identify athletes at higher risk for ACL injury. The purpose of this study was to evaluate the cost-effectiveness of these training methods and screening strategies for preventing ACL injuries.

Methods: A decision-analysis model was created to evaluate three strategies for a population of young athletes participating in organized sports: (1) no training or screening, (2) universal neuromuscular training, and (3) universal screening, with neuromuscular training for identified high-risk athletes only. Risk of injury, risk reduction from training, and sensitivity and specificity of screening were based on published data from clinical trials. Costs of training and screening programs were estimated on the basis of the literature. Sensitivity analyses were performed on key model parameters to evaluate their effect on base case conclusions.

Results: Universal neuromuscular training of all athletes was the dominant strategy, with better outcomes and lower costs compared with screening. On average, the implementation of a universal training program would save $100 per player per season, and would reduce the incidence of ACL injury from 3% to 1.1% per season. Screening was not cost-effective within the range of reported sensitivity and specificity values.

Conclusions and Clinical Relevance: Given its low cost and ease of implementation, neuromuscular training of all young athletes represents a cost-effective strategy for reducing costs and morbidity from ACL injuries. While continued innovations on inexpensive and accurate screening methods to identify high-risk athletes remain of interest, improving existing training protocols and implementing neuromuscular training into routine training for all young athletes is warranted.

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Youth participation in organized sports plays a major role in the physical, social, and financial well-being of athletes and their families. Participation in sports among youth in both high school and college has been steadily increasing; three-quarters of U.S. households have children who play sports[1], and female participation in particular is on the rise[2,3].

This increased athletic participation has inevitably resulted in more injuries, with >3.5 million sports injuries reported annually for children under fourteen years old[1,4], which includes an increased number of anterior cruciate ligament (ACL) ruptures[5]. ACL injuries can be physically and psychologically devastating to young athletes[6], and at a minimum require prolonged withdrawal

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A commentary by Charles J. Gatt Jr., MD, is linked to the online version of this article at jbjs.org.

from sports as well as substantial expenses related to surgical costs and therapy[7-10]. Even with reconstruction, return to competition has been reported to be as low as 50%[11-15].

Several recent studies have evaluated the pathomechanics and risk factors for ACL injury. Epidemiological studies have shown that the prevalence of ACL injuries is four to six times higher in females than males[16-18], while biomechanical studies have shown that women tend to have both anatomic and neuromuscular differences compared with men[16,19-21]. These theories have been corroborated by prospective kinematic studies that have shown that athletes who land with increased knee abduction moment are at a higher risk of subsequent ACL injury[22].

On the basis of this theory of altered neuromuscular control, several prevention programs that focus on retraining athletes to jump, land, and cut in biomechanical positions that reduce the strain on the ACL have been developed[23-27]. These programs have been prospectively tested in multiple studies[25-35], and recent meta-analyses have shown they are effective in lowering the rate of ACL injuries[36,37].

Widespread implementation of new training programs, however, would require additional costs that have not been well described. Some authors have also proposed various potential screening tests to identify individual athletes at higher risk for ACL injury as candidates for intervention[22,38-42].

A better understanding of the trade-offs between these two approaches could aid physicians, athletic trainers, researchers, and policy makers in determining if (a) the additional cost of implementing a universal prevention program would reduce the prevalence of injuries in a cost-effective manner or (b) if a screening tool would allow us to more efficiently focus resources on athletes with a higher risk of injury.

The primary objective of this study was to establish a model to evaluate the cost-effectiveness of neuromuscular training methods and screening strategies aimed at reducing the morbidity associated with ACL injury. Additionally, we aimed to describe the costs and performance of these training and screening techniques that would be required to become optimally cost-effective.

Materials and Methods

Study Design

We conducted an economic evaluation using a decision analytic model, following guidelines by the Panel on Cost-Effectiveness in Health and Medicine[43]. Our reference case was a hypothetical cohort of athletes involved in organized sports, as that is a group in which broad-based interventions are feasible and high-quality data exist. The cohort included athletes between the ages of fourteen and twenty-two years (high school and college). Both males and females were included, as the literature has not clearly demonstrated a difference in training effectiveness between sexes. The literature included athletes participating in soccer, handball, volleyball, and basketball, which can broadly be categorized as "cutting sports."

Costs were calculated from a societal perspective. We used a twenty-year time horizon, based on the longest follow-up data available on patients with ACL injuries[44,45]. Outcomes were expressed in quality-adjusted life years (QALYs), which takes into account decrements in quality of life due to disease and/or injury as well as the time over which those changes occurred[43].

A decision tree model was created and analyzed using decision analysis software (TreeAge Pro; TreeAge Software, Williamstown, Massachusetts). The model compared multiple intervention strategies; for each strategy, the model predicted resulting outcomes (ACL reconstructed or no ACL injury) with defined probabilities (e.g., positive test, negative test, or ACL injury; see Appendix). The probabilities, costs, and outcomes were assigned values, which provided average expected-value outcomes for each strategy.

Model Design

A decision tree was constructed for evaluation of the total costs and gains in QALYs on the basis of three strategies: (a) no training or screening, (b) enrolling all athletes in neuromuscular training programs, or (c) screening all athletes for risk of ACL injury, and enrolling only so-called high-risk athletes in neuromuscular training programs (see Appendix). We assumed that all ACL ruptures would be surgically reconstructed, which is more cost-effective than conservative treatment[8,46-49] and is a widely accepted treatment with the intent of restoring joint kinematics, returning athletes to sport, and limiting disability[50-52].

The neuromuscular training program was based on published trials, which typically involve a specific training drill during practice and an altered warm-up routine[36,53]. In general, these protocols involve specific warm-up activities, core and lower extremity stretching, strengthening, plyometrics, and sport-specific agility drills, usually performed around twenty minutes before practice, three times weekly. They emphasize muscle balance, proprioception, and core strength to reinforce proper mechanics during unanticipated landing or cutting. The screening program was modeled after studies that used anthropomorphic data and kinematic measurements obtained from a video camera during a simple drop-jump test to predict the risk of subsequent ACL injury[38-40].

Model Inputs (Table I)

Costs

The main cost inputs in this model were those associated with ACL reconstruction, the neuromuscular training and injury prevention program, and the risk assessment or screening program. Costs for ACL reconstruction, which were based on previous literature, have been reported to range from $5000 to $17,000[7-10,46], although some recent studies have estimated the long-term societal costs to be as high as $38,000 for operatively treated injuries[49].

The costs of the training programs were based on the programs that have been described in prospective comparative trials[26,28-32,34]. We estimated the resources required on the basis of both personnel and equipment needs. The costs in our reference case were based on the routine described by Mandelbaum et al.[26], which included additional training for the coach (watching instructional videos online) and additional training for the team (learning how to execute the new routine). Assuming the coach takes thirty minutes to watch the instructional materials at the beginning of each season, and an additional thirty minutes to teach the routine to the players, the cost would be $1.25 per player per season (assuming the coach is salaried at $50,000 yearly[54], and the average team size is twenty players). A higher cost estimate, which we evaluated in the sensitivity analysis, was based on the study by Hewett et al.[31], which involved preseason sessions with a dedicated athletic trainer for sixty to ninety minutes for a total of eighteen sessions, increasing the cost estimate to $25 per player per season.

The cost of a potential screening program was estimated on the basis of the protocols reported in the literature. Protocols requiring extensive setup and sophisticated biomechanical monitoring equipment[22] were excluded, as the expense and time required to conduct these would not be conducive to large-scale screening.

The more feasible protocols follow a common set of steps, which involve (a) gathering anthropomorphic data on the subject, then (b) videotaping a drop jump to analyze the kinematics, and (c) performing simple calculations to estimate the injury risk[39,40]. Under the most optimistic estimates, a dedicated screening center with minimal equipment (two cameras and one computer) and full-time staff salaried at $50,000 yearly would take at least five minutes per subject (including registration, data gathering, and analysis), which would cost approximately $2 to $3 per player screened. If, instead, the screening was performed by coaches or athletic trainers using similar equipment, the equipment cost per player increases and the cost per screening would rise to $15 per player. If coaches or athletic trainers were able to perform a screening test without cameras or equipment, the cost would drop to $1.50 per player screened.

Clinical Outcome Probabilities

The baseline ACL injury rate, which was based on multiple prospective studies[17,25-32,34], ranged from 0.003 to 0.08 per player per season. Although there were a few outliers, the

TABLE I Input Values Used to Calculate the Cost-Effectiveness of Prevention Strategies for ACL Ruptures*

Description	Value: Base Case	Low	High	Studies
Surgical costs				
ACL reconstruction *($)*	8000	5000	17,000	Gottlob et al.[7], Lubowitz and Appleby[8], Paxton et al.[9], Genuario et al.[10], and Farshad et al.[46]
Risk of ACL injury				
Baseline incidence of ACL rupture (per season)	0.03	0.02	0.04	Arendt and Dick[17], Myklebust et al.[25], Mandelbaum et al.[26], Steffen et al.[27], Caraffa et al.[28], Gilchrist et al.[29], Heidt et al.[30], Hewett et al.[31], Petersen et al.[32], and Pfeiffer et al.[34]
Prevention program				
Cost of prevention program *($/player/yr)*	1.25	1.25	25	Mandelbaum et al.[26], Caraffa et al.[28], Gilchrist et al.[29], Heidt et al.[30], Hewett et al.[31], Petersen et al.[32], and Pfeiffer et al.[34]
Risk ratio of prevention program	0.38	0.2	0.72	Sadoghi et al.[36]
Screening test				
Cost of screening test *($/player)*	1.5	0	15	Uhorchak et al.[20], Hewett et al.[22], Padua et al.[38], and Myer et al.[42]
Sensitivity of screening test	65	61	78	Hewett et al.[22] and Myer et al.[39-41]
Specificity of screening test	60	56	73	Hewett et al.[22] and Myer et al.[39-41]
Quality of life *(utility value)*				
After ACL reconstruction	0.78	0.72	0.98	Gottlob et al.[7], Lubowitz and Appleby[8], Paxton et al.[9], Genuario et al.[10], Farshad et al.[46], Biau et al.[56], and Tibor et al.[57]

*ACL = anterior cruciate ligament.

data were relatively consistent, with >70% of studies noting injury rates between 0.02 and 0.03. An incidence of 0.03 was used in the reference case, with a range of 0.02 to 0.04 used in the sensitivity analysis.

The reduction in injury from prevention programs was based on a recent meta-analysis that reported a mean risk ratio of 0.38 (i.e., a 62% reduction in risk; 95% confidence interval, 0.2 to 0.72)[36].

Sensitivity and Specificity of Screening

There are no published reports of the diagnostic performance of simple jump tests for predicting ACL injury. In order to determine overall sensitivity and specificity, data from previous studies examining two types of tests were combined. Hewett et al. created a gold-standard screening test for predicting ACL injury, using measured knee abduction moments in 205 patients who were prospectively followed, and found a sensitivity of 78% and specificity of 73% for subsequent ACL rupture[22]. However, these data required use of a sophisticated motion capture laboratory, which is not feasible for large-scale implementation. Alternatively, there are lower-cost studies that have described the use of simple anthropometric measurements, a camcorder, and free software that uses a single drop jump to predict a high knee abduction moment, with reported sensitivities ranging from 73% to 84% and specificities, from 67% to 71%[39-41]. The data from these two tests were combined; one set used simple equipment to predict knee abduction moment, and another used more elaborate protocols that measured knee abduction moment and predicted ACL injury. The data were synthesized to calculate an effective sensitivity and specificity of simple jump tests for ACL injury (sensitivity ranged from 61% to 70% and specificity, from 56% to 61%).

Health-Related Quality of Life (Health Utility)

Health-related quality of life was calculated on the basis of the literature on subjective outcomes after ACL reconstruction[7-10]. Most literature currently has described outcomes after ACL reconstruction using International Knee Documentation Committee (IKDC) scores ranging from A (perfect function during stressful sports) to D (symptomatic pain and/or instability during activities of daily living). Utilities were derived from those measured in a survey of 285 university students by Gottlob and Baker[48], which was later adapted to the IKDC scale by Paxton et al.[9]. After ACL reconstruction, patients were assigned health utilities on the basis of the IKDC score, which was distributed according to those reported in recent meta-analyses (Table II). We used a weighted average of the IKDC score breakdowns to generate the utility in the reference case.

Sensitivity Analysis

Sensitivity analysis was performed to evaluate the uncertainties in key parameter values. The ACL rupture rate, reconstruction cost, utility after reconstruction, and time horizon were varied in a series of one-way sensitivity analyses. A multiway sensitivity analysis was also performed to evaluate the combined uncertainties of the training program cost, risk reduction with training, screening program cost, and screening program sensitivity and specificity.

Finally, we evaluated a hypothetical scenario in which a novel, more intensive neuromuscular training program was developed. All athletes would be trained under the current neuromuscular program, but those identified as at risk would be given additional training in the novel program. We then conducted a threshold analysis to answer the question: If this hypothetical training

TABLE II Outcomes by International Knee Documentation Committee (IKDC) Group and Corresponding Utility

Analysis	No. of Subjects	Percent in Each IKDC Group (Utility*)				Overall Average Utility
		A (1.0)	B (0.697)	C (0.328)	D (0.233)	
Gottlob et al.[7]	373	66.5	23.9	6.3	3.3	0.86
Paxton et al.[9]	989	59.3	34.4	5.8	0.5	0.85
Biau et al.[56]	1125	37.1	41.5	21.4†		0.73
Tibor et al.[57]	1970	39	43.8	13.3	3.9	0.75
Model		45.3	39.5	13.1	2.1	0.78

*Based on initial data by Gottlob et al.[7]. †In Biau et al.[56], the percentage in groups C and D were combined for a total of 21.4%.

program were used, what are the cost and risk reduction parameters for which universal screening would be cost-effective?

Source of Funding

There was no external funding for this investigation.

Results

Reference Case

Universal training was estimated to reduce the incidence of ACL injury by an average of 63% (from 3% per season to 1.1% per season), while the screening program reduced the incidence by an average of 40% (from 3% to 1.8%). In other words, the model predicted that, of 10,000 athletes, 300 would have ACL injuries in the no-screening arm; 110, in the treat-all arm; and 180, in the screen-and-treat arm. On a per-case basis, the average cost of the universal training strategy was $100 lower than no training and $25 lower than screening. The universal training strategy also results in a net gain of 0.05 QALY, on average, compared with no training and an average gain of 0.03 QALY compared with screening. Universal training was therefore the dominant strategy, resulting in lower costs overall as well as improved health outcomes.

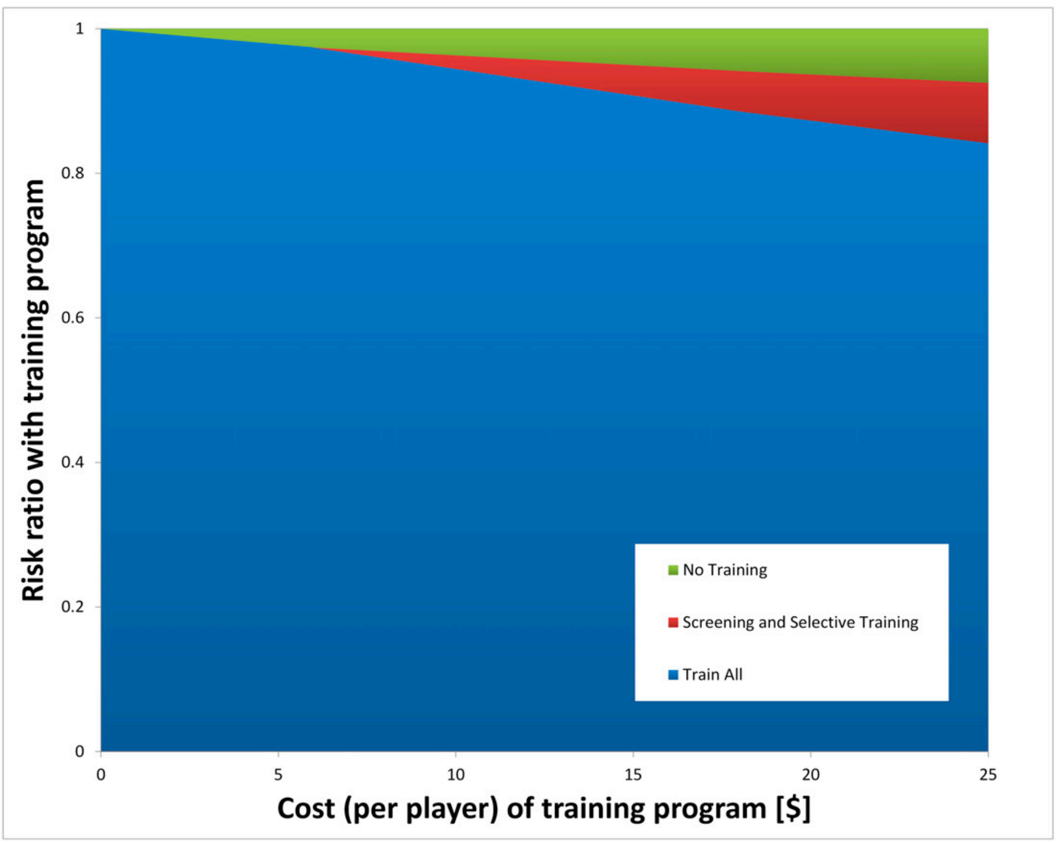

Fig. 1

Effect of training cost and training risk reduction on the model. Two-way sensitivity analysis evaluating the cost of the training program and the risk ratio (effectiveness) of the training program. As shown, universal training dominated for all risk ratios below 0.9, with a narrow range of cost/risk ratio values where screening would be cost-effective.

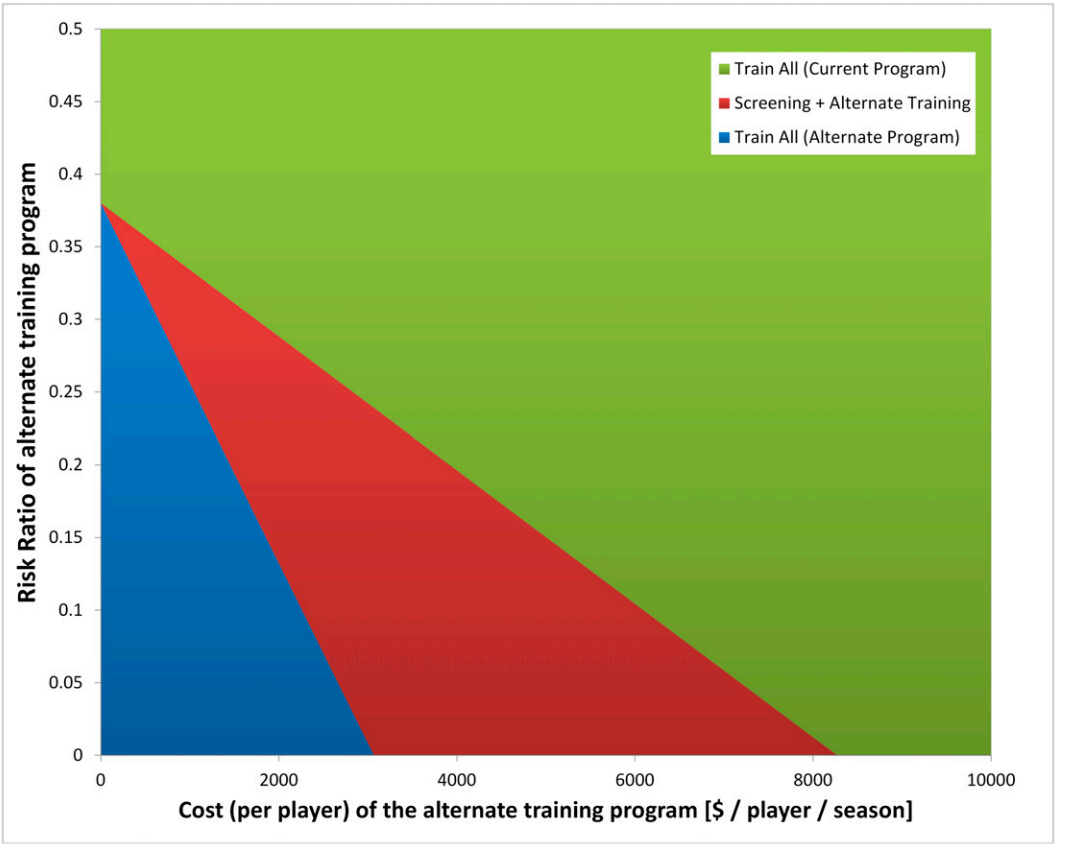

Fig. 2
Effect of hypothetical training program cost and risk reduction. Two-way sensitivity analysis evaluating cost and risk ratio of a hypothetical new training program. For highly effective (i.e., low risk ratio) and inexpensive new programs, universal training under the new program is cost-effective (blue area). For a narrow range of moderately effective, fairly expensive new programs, screening prior to implementation becomes cost-effective (red area). When the new training program is expensive and less effective, it is less cost-effective than current training programs (green area).

Sensitivity Analyses

In all of the one-way sensitivity analyses, in which parameters were varied according to the ranges specified in Table I, universal training was the dominant strategy. The results remained unchanged for ACL reconstruction costs as low as $1000 and ACL injury rates as low as 0.001 per player per season. The cost of the training program and its risk reduction were more influential parameters, although universal training still dominated other alternatives for almost all parameter values tested (Fig. 1). Two-way sensitivity analysis evaluating both sensitivity and specificity of the screening test showed that universal training remained dominant for all values.

Hypothetical Training Scenario

Assuming a societal willingness to pay $100,000/QALY[55] in a hypothetical scenario, in which a new training program is more costly but also more effective, universal training with the novel protocol could be cost-effective if the cost was <$2500 per player per season (Fig. 2). If the cost of the training is between $3000 and $8000 and reduces injury risk by at least 80% (relative risk of <0.2), universal screening would become the cost-effective option. Protocols requiring expenses of >$8000 per player were unlikely to be more cost-effective than current protocols.

Discussion

Our study compared the effectiveness and cost-effectiveness of two approaches to lower the risk of ACL injury in young athletes: training everyone or training high-risk athletes identified by screening. When a proposed screening and prevention protocol for any medical problem is evaluated, careful consideration has to be given to the costs and accuracy of screening as well as the cost and effectiveness of prevention in light of the economic and social burden of the disease. If the potential treatments cannot alter the course of disease, screening is ineffective, no matter how inexpensive or accurate. Likewise, potential treatments may be efficacious, but if there is no way to accurately identify at-risk patients, it can be difficult to efficiently allocate resources.

In this study, the universal neuromuscular training strategy was cost-effective in virtually all situations for several reasons. First, the injury is common, and is associated with a large cost due to a high rate of surgical treatment. Furthermore, the neuromuscular training programs have a relatively low cost coupled with a large demonstrable risk reduction, making primary prevention the dominant strategy.

There were virtually no scenarios in which universal screening was cost-effective. This makes intuitive sense, as the cost of training is low, the effectiveness of prevention is rather high, and the prevalence of injury is relatively high; in this context, it is unlikely that a screening test would be able to outperform universal training. This argues in favor of future investigations focusing on increasing the performance or efficiency of neuromuscular training regimens, rather than on improving or implementing screening tests.

The rationale for analyzing the hypothetical training scenario was done to determine if there was any scenario in which universal screening would be appropriate. The results of that analysis show that screening reduces costs only when there are extremely effective training interventions that are also expensive. Anecdotally, there are currently several different ACL prevention programs in use at more elite levels that are more resource intense in which this scenario might exist; however, as far as we know, there is currently no published literature on interventions of this type. Our hope is that these findings might help set goals for future research and act as a proof of concept that expensive, intense training techniques could be cost-effective if coupled with efficient screening programs.

One of the strengths of this analysis is the relatively large amount of data from prospective, high-quality studies, which can improve our confidence in the accuracy of the results. This was further confirmed by sensitivity analyses with respect to injury rate, reconstruction cost, and time horizon, which demonstrate the robustness of the model's conclusions. Although a recent meta-analysis has shown prevention programs to be effective[36], the magnitude of the effect remains debatable. While variability in the risk reduction may change the final incidence of ACL injury and cost savings, the most cost-effective strategy remains universal training for the entire range of values used in this model.

The post-ACL reconstruction utility was based on the current literature, but was fairly low in the reference case, so a broader range of utilities was tested in sensitivity analysis. In general, we made conservative estimates about the morbidity of ACL injury to avoid inflation of the apparent value of prevention tools. Additionally, we did not evaluate the possibility that some of the injured athletes may choose not to undergo ACL reconstruction. As all of the available literature currently suggests that reconstruction is more cost-effective[7,8,46], patients choosing nonoperative treatment could have correspondingly worse outcomes, which would only further exaggerate the benefit of prevention. Despite these estimates, a widespread implementation of neuromuscular training programs continues to dominate as the most cost-effective strategy, although future research should continue to carefully scrutinize the loss of utility after ACL injury.

One of the limitations of the study was the lack of primary cost data for both training and screening programs. As a result, several assumptions were required to generate cost estimates to complete the model. Our sensitivity analysis shows that our conclusions are consistent for a wide variety of costs, including some that were more than an order of magnitude higher than our estimates. In fact, training costs would have to increase >$200 per player per season before cost-effectiveness came into question. Future research that generates more accurate cost estimates within the bounds of our sensitivity analyses for both training and screening protocols is needed to confirm our findings.

It should also be clarified that these results are applicable only to high school, college, and professional athletes who participate in regular, organized practices where formal alterations in warm-ups and additional training routines can be consistently implemented. Although we did not run subanalyses using sex or sport-specific injury rates, our sensitivity analysis showed that our results are consistent for a wide range of injury rates that would include these more specific estimates. However, we cannot make conclusions about how effective these programs would be in children under fourteen years old, those who participate in recreational-level sports, or older athletes.

In conclusion, this model shows that universal prevention in focused neuromuscular training can represent a cost-effective strategy for reducing the morbidity and costs associated with ACL injuries. The results are based on a large body of high-quality published literature and are broadly robust when tested with sensitivity analyses. Screening for high-risk athletes is currently not cost-effective; however, if the costs are reduced and accuracy is improved, there may be a role for screening coupled with more focused and resource-intensive training programs. Future research should focus on improving and universally implementing these programs, rather than improving screening, which these analyses have shown not to be cost-effective.

Appendix

eA A figure showing a schematic representation of the decision tree model is available with the online version of this article as a data supplement at jbjs.org. ■

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