

Role of prevent injury and enhance performance program in improving dynamic knee alignment and neuromuscular control following acl rehabilitation in football players: A narrative review

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Abstract: Background: Anterior cruciate ligament (ACL) injury is a common concern among football players. Neuromuscular deficits, poor landing mechanics, and abnormal dynamic knee alignment may contribute to the risk of ACL injury and re-injury. The Prevent Injury and Enhance Performance (PEP) program incorporates stretching, strengthening, plyometric, and agility exercises aimed at improving neuromuscular control and movement quality.

Objective: To review the role of the PEP program in improving dynamic knee alignment and neuromuscular control following ACL rehabilitation in football players.

Methods: A narrative literature review was conducted using PubMed and Google Scholar. Studies published in English between 2015 and 2026 were considered. Studies involving football players following ACL injury or reconstruction and evaluating the PEP program or related neuromuscular and proprioceptive training interventions were included. Outcomes included dynamic knee alignment, neuromuscular control, proprioception, landing mechanics, postural stability, functional performance, and ACL re-injury prevention.

Results: Twelve relevant studies were identified. Overall, the evidence suggested that PEP and related neuromuscular training interventions may improve landing mechanics, postural stability, neuromuscular control, hip and knee biomechanics, and dynamic knee valgus in football players. Studies involving athletes following ACL reconstruction also reported improvements in postural control and landing-related outcomes. However, direct evidence regarding the effect of PEP on dynamic knee alignment following ACL rehabilitation remains limited.

Conclusion: The PEP program may be a useful adjunct to ACL rehabilitation for improving neuromuscular control, landing mechanics, and dynamic knee stability in football players. However,

further high-quality studies involving larger post-ACL reconstruction populations, standardized PEP protocols, direct assessment of dynamic knee alignment, and longer follow-up are needed to determine its effectiveness in reducing ACL re-injury and supporting a safe return to football.

Keywords: PEP programme, knee alignment, neuromuscular control, football players

INTRODUCTION

Soccer is widely recognised for its health benefits among young athletes; however, participation also exposes them to a considerable risk of sports-related injuries, particularly during training and competitive play. Injuries affecting the lower extremities are especially prevalent among preadolescent soccer players, with reported incidence rates of approximately 2.3–6.4 injuries per 1,000 hours of athlete exposure and the highest occurrence observed around 13 years of age. An increasing incidence of anterior cruciate ligament (ACL) injuries in children and preadolescents is particularly concerning, as these injuries may adversely affect both the physical performance and psychological well-being of young athletes ^[1]. Despite the implementation of injury-prevention programs, serious injuries such as non-contact anterior cruciate ligament (ACL) ruptures continue to occur. Furthermore, recent evidence indicates an increasing incidence of ACL injuries among children and adolescents, raising concerns regarding their potential impact on the physical and psychological development of young athletes. Therefore, there is a need to explore targeted preventive strategies that can complement existing injury-prevention programs. Such interventions may specifically address modifiable risk factors associated with injury, including impaired neuromuscular control, which may be reflected by excessive dynamic knee valgus and reduced dynamic balance [2].

Abnormal jump-landing mechanics, characterised by greater vertical ground reaction forces (vGRF), reduced hip and knee flexion, and increased knee abduction and internal rotation, may contribute to excessive dynamic knee valgus and are associated with an elevated risk of a second ACL injury. These modifiable biomechanical risk factors may be addressed through targeted neuromuscular training before athletes return to unrestricted sports participation [3].

The Prevention Injury and Enhance Performance (PEP) program has been shown to reduce the risk of both primary and recurrent anterior cruciate ligament (ACL) injuries, particularly following ACL reconstruction. The program emphasises neuromuscular control to improve lower-limb stability and maintain proper dynamic knee alignment during functional and sportsspecific movements. It includes stretching, strengthening, plyometric, and agility exercises, which together enhance movement coordination and help reduce excessive knee valgus associated with ACL injury [4].

Several studies have demonstrated that training strategies such as plyometric, stretching, isometric, and strengthening exercises can help reduce the incidence of ACL injuries. Lehnhart also suggested incorporating neuromuscular training as an additional approach for injury prevention. In 2005, Mandelbaum introduced the Prevent Injury and Enhance Performance (PEP) program, which aimed to reduce ACL injury risk through exercises involving eccentric, isometric, and concentric muscle actions targeting the hamstrings and quadriceps. The PEP program emphasizes proper exercise technique, appropriate body posture, and controlled landing mechanics. The program can be completed in approximately 20 minutes, making it practical for integration into regular football training [5].

MATERIALS AND METHODS

Strategy of Search

A comprehensive literature search was conducted using the electronic databases PubMed and Google Scholar to identify relevant studies related to the role of the Prevention Injury and Enhance Performance (PEP) program in improving dynamic knee alignment and neuromuscular control following ACL rehabilitation in football players. Articles published between 2019 and 2026 were considered for inclusion. The search included original research studies, randomized controlled trials, clinical investigations, systematic reviews, scoping reviews, and narrative reviews relevant to ACL rehabilitation.

PICO Evaluation

The review was guided by the PICO framework. The Population (P) included football players who had undergone ACL reconstruction and completed or were undergoing ACL rehabilitation. The Intervention (I) consisted of the Prevention Injury and Enhance Performance (PEP) program, with emphasis on neuromuscular and proprioceptive training. The Comparison (C) included conventional ACL rehabilitation, usual care, or rehabilitation without the PEP program. The Outcomes (O) included improvements in dynamic knee alignment, neuromuscular control, proprioception, landing mechanics, functional performance, and ACL re-injury prevention.

Inclusion Criteria

Studies published in English between 2015 and 2026 involving football players following ACL injury or reconstruction were considered for inclusion. Studies investigating the PEP program

or related neuromuscular and proprioceptive training interventions, with outcomes related to dynamic knee alignment, neuromuscular control, proprioception, landing mechanics, functional performance, or ACL injury/re-injury prevention, were included.

Exclusion Criteria

Editorials, conference abstracts, letters to the editor, duplicate publications, non-English articles, and studies unrelated to ACL rehabilitation, PEP program, dynamic knee alignment, neuromuscular control, or football players were excluded. Studies with insufficient methodological information, inadequate reporting of relevant outcomes, or insufficient data to support interpretation of the findings were also excluded.

Data Extraction and Classification

Relevant information from the studies included in the review was extracted, including the author, year of publication, study design, participant characteristics, ACL reconstruction status, PEP program intervention, outcome measures, key findings, and reported limitations. The studies were subsequently classified according to the type of intervention and its effects on dynamic knee alignment, neuromuscular control, and ACL reconstruction among football players.

Risk of Bias Assessment

Although this review was narrative in nature, the methodological quality of the included studies was critically evaluated by considering the study design, participant characteristics, intervention characteristics, sample size, outcome measures, and clarity of the reported findings. Particular attention was given to the methods used to assess dynamic knee alignment, neuromuscular control, proprioception, and ACL injury or re-injury outcomes following rehabilitation. Studies with adequate methodological quality, clearly described interventions, appropriate outcome measures, and greater relevance to the review objectives were given greater emphasis during the evidence synthesis.

Data Synthesis Strategy

The findings of the included studies were synthesized narratively according to the principal outcomes relevant to the objectives of the present review, namely dynamic knee alignment, neuromuscular control, and jump-landing biomechanics. Particular attention was given to studies involving football or soccer players and to evidence obtained following anterior cruciate

ligament (ACL) reconstruction. The evidence was further considered according to intervention characteristics, including the use of the Prevent Injury and Enhance Performance (PEP) program, related neuromuscular training protocols, proprioceptive exercises, and injury prevention warm-up programs. To facilitate interpretation, studies involving athletes following ACL reconstruction were considered separately from studies conducted in non-reconstructed or healthy football players.

Effects of PEP and neuromuscular training on dynamic knee alignment:

Dynamic knee alignment is an important biomechanical consideration in ACL injury prevention and rehabilitation because inadequate control of the hip, knee, and trunk during landing and other high-demand sporting tasks may contribute to excessive frontal-plane knee motion. Several studies have therefore examined whether injury-prevention and neuromuscular training programs can modify lower-extremity movement patterns during functional tasks.

Pollard et al. investigated the effects of ACL injury-prevention training on hip and knee mechanics during a drop-landing task and demonstrated that neuromuscular training can modify lower-extremity movement strategies during landing. Similarly, García-Luna et al. examined the acute effects of an ACL injury-prevention warm-up combined with a soccer-specific fatigue protocol and evaluated dynamic knee valgus in youth male soccer players. These findings are relevant to the present review because they indicate that neuromuscular warm-up strategies may influence frontal-plane knee mechanics even under conditions of sport-specific fatigue.

Evidence from longitudinal interventions further suggests that repeated exposure to injury prevention exercises may influence landing technique. Lindblom et al. evaluated an eight-week injury-prevention exercise program in youth football players and reported changes in jump landing technique, although the magnitude and direction of the effects differed according to sex. Such findings highlight the possibility that adaptations to neuromuscular training may be influenced by participant characteristics and baseline movement patterns.

Studies specifically examining the PEP provide additional evidence regarding its potential role in modifying movement strategies. Rodriguez et al. evaluated the effects of the Prevent Injury and Enhance Performance Program in female soccer players, while Babu Kaiyaperumal et al. investigated PEP combined with proprioceptive training in football players following ACL reconstruction. Collectively, these studies provide a basis for considering PEP as a structured

intervention targeting neuromuscular and lower-extremity control. However, differences in participant characteristics, intervention protocols, and outcome measures should be considered when interpreting findings across studies.

Effects on neuromuscular control

Neuromuscular control represents another major outcome domain relevant to the prevention of recurrent ACL injury. Following ACL reconstruction, deficits in proprioception, balance, movement coordination, and lower-extremity control may persist despite completion of conventional rehabilitation. Consequently, interventions that challenge balance, proprioception, coordination, and controlled movement may have clinical relevance during the transition from rehabilitation to unrestricted sporting activity.

Ghaderi et al. examined a neuromuscular training program in male athletes following ACL reconstruction and evaluated the influence of external-focus attention cues on movement-related outcomes. The study contributes to the growing evidence that neuromuscular training can be incorporated into ACL rehabilitation to address movement-control deficits. Dalvandpour et al. similarly investigated the influence of attentional focus during ACL injury prevention exercises on jump-landing kinematics in soccer players, suggesting that not only the exercise content but also the manner in which exercises are performed may influence biomechanical adaptations.

The findings from these studies collectively suggest that injury-prevention and neuromuscular programs may influence several components of neuromuscular control, including balance, proprioceptive regulation, and the ability to control lower-extremity movement during dynamic tasks. Nevertheless, variation in assessment techniques makes direct comparison between studies difficult.

Effects on jump-landing biomechanics:

Jump landing has been frequently used to evaluate neuromuscular control and dynamic knee alignment because it requires coordinated control of the trunk, hip, knee, and ankle. Several studies included in this review used landing-based tasks to investigate the effects of injury prevention or neuromuscular interventions.

Pollard et al. reported modifications in hip and knee mechanics following ACL injury prevention training, supporting the use of landing tasks for evaluating biomechanical adaptations. García-Luna et al. further examined dynamic knee valgus following an

injury prevention warm-up in youth soccer players, including the influence of soccer-specific fatigue. Lindblom et al. assessed changes in jump-landing technique following eight weeks of injury prevention exercise training, whereas Dalvandpour et al. investigated whether attentional focus during ACL injury-prevention exercises influenced subsequent jump-landing kinematics.

Studies involving athletes after ACL reconstruction provide additional clinical relevance. Ashigbi et al. evaluated the acute effects of a neuromuscular warm-up on potential reinjury-related factors during unanticipated jump landings following ACL reconstruction. This study is particularly pertinent because unanticipated landing tasks more closely resemble the unpredictable movement demands encountered during football than predictable laboratory-based landing tasks. Friebe et al. similarly examined the acute effects of an injury-preventive warm-up on unanticipated jump-landing task performance in adult football players.

Taken together, these studies indicate that jump-landing tasks provide a useful framework for evaluating the effects of injury-prevention interventions on lower-extremity biomechanics. However, acute changes observed immediately following a warm-up should be distinguished from adaptations resulting from repeated training over several weeks.

Evidence specifically following ACL reconstruction:

The evidence involving athletes following ACL reconstruction is particularly relevant to the present review because the primary focus is the role of PEP following ACL rehabilitation. Among the included studies, Ghaderi et al., Babu Kaiyaperumal et al., Ghorbani et al., and Ashigbi et al. provide evidence involving participants with a history of ACL reconstruction.

Babu Kaiyaperumal et al. specifically examined PEP combined with proprioceptive training in football players following ACL reconstruction, making this study directly relevant to the intervention and population of interest. Ghorbani et al. also examined PEP in soccer players with and without ACL reconstruction, with postural control serving as an important neuromuscular outcome. Ghaderi et al. investigated neuromuscular training following ACL reconstruction, while Ashigbi et al. examined the acute effects of neuromuscular warm-up on landing-related factors in reconstructed athletes.

These studies provide evidence that neuromuscular and proprioceptive training may be relevant beyond the restoration of basic strength and range of motion following ACL reconstruction. In particular, the incorporation of dynamic balance, landing control, and sport-specific movement challenges may address movement deficits that can remain during the later stages of

rehabilitation. However, the available literature remains heterogeneous with respect to rehabilitation stage, intervention duration, training frequency, outcome measures, and participant characteristics.

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Direct and indirect evidence for the PEP program:

The available literature can also be differentiated according to whether the intervention used the PEP protocol specifically or employed a broader ACL injury-prevention or neuromuscular training approach. Rodriguez et al., Babu Kaiyaperumal et al., Arranz de la Fuente et al., and Ghorbani et al. provide more direct evidence regarding the PEP program. In contrast, studies by Pollard et al., García-Luna et al., Lindblom et al., Ashigbi et al., Friebe et al., Ghaderi et al., and Dalvandpour et al. provide supporting evidence from related injury-prevention or neuromuscular interventions.

This distinction is important because findings from related neuromuscular programs cannot automatically be attributed to PEP itself. Nevertheless, such studies can provide mechanistic

support for the exercise components and neuromuscular principles incorporated within injury prevention programs. Accordingly, the evidence should be interpreted according to both the specificity of the intervention and its relevance to athletes following ACL reconstruction.

RESULTS

A total of 14 studies published between 2015 and 2026 were identified as relevant to the present narrative review. The selected studies included randomized controlled trials, randomized clinical trials, crossover trials, prospective studies, and intervention studies evaluating the Prevent Injury and Enhance Performance (PEP) program and related neuromuscular training interventions in football and soccer players. Considerable clinical and methodological heterogeneity was observed regarding participant characteristics, ACL reconstruction status, intervention protocols, duration of training, study designs, and outcome measures. The outcomes assessed included dynamic knee alignment, neuromuscular control, proprioception, landing mechanics, postural stability, functional performance, and ACL injury or re-injury risk. The findings were narratively synthesized according to the predefined objectives of the review, with particular emphasis on the role of PEP in improving dynamic knee alignment and neuromuscular control following ACL rehabilitation in football players.

Research Gaps in Low-Resource Settings

Research investigating the PEP program following ACL rehabilitation is still limited in low resource settings, particularly among football players. Most available studies have been conducted in developed countries and well-equipped sports or research facilities, with limited evidence from developing countries, including India. There is a lack of studies examining the feasibility and effectiveness of PEP using low-cost and easily accessible assessment methods for dynamic knee alignment and neuromuscular control. Furthermore, limited research has evaluated the long-term effectiveness of PEP in post-ACL reconstruction football players, particularly in relation to second ACL injury and return to sport. Future research should focus on larger samples, standardized PEP protocols, longer follow-up periods, and cost-effective methods for assessing dynamic knee alignment and neuromuscular control that can be implemented in resource-limited football and physiotherapy settings.

Factors Influencing the Adoption

The adoption of the PEP program may be influenced by athlete adherence, coach and physiotherapist support, availability of trained professionals, time constraints, and access to

facilities. It is simple and low-cost exercises make PEP suitable for football and low-resource settings. Proper supervision and regular integration into training are important for effective implementation.

Table1: Summary of included studies

Authors (year)	Study design	Main outcome	Main findings	Clinical relevance
Kaliyaperumal et al. (2022)	Quasiexperimental comparative study	IKDC score and Single-Leg Hop Test	PEP with proprioceptive training improved neuromuscular control and may reduce recurrent ACL injury risk following ACL reconstruction.	Supports PEP and proprioceptive training for ACL re-injury prevention in football players.
Dalvandpour et al. (2023)	Randomized controlled trial	Jump-landing kinematics	Eight weeks of PEP with an external focus improved hip and knee flexion kinematics during landing compared with internal focus. After 24 weeks of PEP, quadriceps and hamstring strength increased and jump mechanics improved in 20% of players; no ACL injury was recorded.	Supports PEP for improving landing mechanics and neuromuscular control in soccer players Supports PEP for improving lowerlimb strength and movement mechanics related to ACL injury prevention.
Rodríguez et al. (2018)	Prospective longitudinal study	Dynamic knee valgus, muscle strength and jump mechanics		

Pollard et al. (2017)	Descriptive laboratory study	Hip and knee biomechanics during drop landing	Twelve weeks of ACL injury prevention training reduced knee extensor moments and increased hip energy absorption, indicating greater	Supports PEP- related training for modifying hip- knee mechanics and reducing potentially
Ashigbi et al. (2021)	Randomized crossover trial	ACL re-injury risk factors during anticipated and unanticipated landing	contribution of the hip during landing. A single PEP warm- up was assessed after ACL reconstruction; decision-making generally improved, although higher peak ground- reaction forces were observed after PEP. The PEP group demonstrated greater improvements in Y- Balance Test and Landing Error Scoring System (LESS) scores compared with the control group, indicating improved dynamic balance and landing control.	harmful knee loading. Supports assessment of PEP as a footballs specific neuromuscular warm-up during post-ACLR return-to-sport preparation. PEP may improve neuromuscular control, dynamic postural stability, and landing mechanics, addressing modifiable risk factors associated with ACL injury in female football players.
Arranz de la Fuente et al. (2019)	Controlled intervention study	Dynamic balance and landing control		

Ghorbani et al. (2025)	Controlled pre–post study	Postural control during singleleg landing	Following 8 weeks of PEP, post-ACLR soccer players showed significant reductions in mean and maximal mediolateral centerof-pressure displacement, indicating improved postural control during landing.	PEP may improve postural and neuromuscular control following ACL reconstruction, supporting its potential role in reducing biomechanical risk factors associated with ACL re-injury.
Friebe et al. (2022)	Randomized crossover trial	Landing stability and decision-making during preplanned and unanticipated single-leg jump-landing tasks. Outcomes	The PEP warm-up significantly reduced CoP trace length by 18.4% ($p = 0.021$) and produced an earlier occurrence of peak vGRF by 4.72% ($p = 0.017$) during	PEP may improve landing stability and neuromuscular control during anticipated landing tasks in football players, supporting its

García-Luna et al. (2020)	Acute experimental study	included centre of pressure (CoP) trace length, peak vertical ground-reaction force (pGRF), standing errors, and landing errors. Dynamic knee valgus during landing	preplanned landing. No significant differences were found for unanticipated landing or decision-making outcomes. ACL injury prevention warm-up influenced dynamic knee valgus, with effects varying after soccer-specific fatigue. Eight weeks of injury-prevention exercise training produced limited improvements in landing technique, with greater effects observed in girls than boys.	potential role in ACL injury prevention training. However, the study did not directly assess dynamic knee alignment or post-ACLR athletes. Supports the use of injury-prevention warmups to improve dynamic knee alignment and reduce potentially risky knee valgus in football players. Suggests that neuromuscular injury-prevention training may improve landing mechanics and neuromuscular control, although responses may differ by gender.
Lindblom et al. (2020)	Controlled intervention study	Jump-landing technique		

DISCUSSION

The findings of the included studies indicate that the Prevent Injury and Enhance Performance (PEP) program and related neuromuscular training interventions can positively influence neuromuscular control and lower-limb biomechanics in football players. This is particularly relevant following ACL rehabilitation, where deficits in movement control, landing mechanics, proprioception, and dynamic knee stability may contribute to the risk of subsequent injury.

Nemati et al. reported improvements in landing kinematics following neuromuscular training in young soccer players with poor landing mechanics, suggesting that targeted training can

modify potentially hazardous movement patterns. Similarly, Wilczyński et al. demonstrated improvements in dynamic knee valgus and balance following strengthening exercises in young football players with poor knee control. These findings support the importance of addressing lower-limb alignment and neuromuscular deficits during ACL rehabilitation [1,2].

Evidence from athletes following ACL reconstruction further supports this approach. Ghaderi et al. found that neuromuscular training using external-focus cues improved movement-related outcomes following ACL reconstruction. Ashigbi et al. also investigated the acute effects of a neuromuscular warm-up on potential re-injury risk factors during unanticipated jump landings after ACL reconstruction. These findings suggest that neuromuscular training may improve movement strategies that are important for safe return to football [3,8].

Several studies specifically examining the PEP program provide additional support. Rodriguez et al. reported beneficial changes following PEP implementation in female soccer players, while Pollard et al. demonstrated that ACL injury-prevention training modified hip and knee mechanics during drop landing. Dalvandpour et al. further showed that the focus of attention during ACL injury-prevention exercises influenced improvements in jump-landing kinematics. Together, these findings suggest that PEP may influence biomechanical factors associated with excessive knee loading and poor landing control [5,6].

The findings of Kaliyaperumal et al. are particularly relevant to the present review because PEP combined with proprioceptive training was investigated in football players following ACL reconstruction. Similarly, Ghorbani et al. reported improvements in postural control following PEP training in soccer players with and without ACL reconstruction. These studies indicate that combining neuromuscular and proprioceptive components may be useful for improving postural stability and neuromuscular control after ACL rehabilitation [4,10].

Friebe et al. reported acute improvements in landing stability following a PEP-based injurypreventive warm-up in adult football players, although improvements were more evident during anticipated rather than unanticipated landing tasks. This suggests that the immediate effects of PEP may vary according to task complexity and the demands placed on reactive neuromuscular control [12].

The high incidence of second ACL injury reported by Della Villa et al. among professional footballers following ACL reconstruction highlights the clinical importance of effective secondary prevention strategies. Although this study did not investigate PEP, its findings

emphasize the need to address modifiable risk factors before and after return to football. PEP may therefore have potential as an adjunct to conventional ACL rehabilitation by targeting neuromuscular control, landing mechanics, proprioception, and dynamic knee stability [11].

Overall, the evidence suggests that PEP can contribute to improvements in neuromuscular control, landing mechanics, postural stability, and lower-limb biomechanics, which are closely associated with dynamic knee alignment. However, direct evidence demonstrating that PEP improves dynamic knee alignment and reduces second ACL injury specifically in post-ACLR football players remains limited. Differences in participant characteristics, intervention duration, outcome measures, and study designs also make direct comparison difficult. Therefore, future research should use standardized PEP protocols, larger post-ACLR football populations, direct measures of dynamic knee alignment, and longer follow-up to determine whether improvements in neuromuscular and biomechanical variables translate into reduced ACL re-injury rates and safer return to sport.

CONCLUSION

The available evidence suggests that the Prevent Injury and Enhance Performance (PEP) program may be beneficial for improving neuromuscular control, dynamic knee alignment, landing mechanics, proprioception, and postural stability in football players. PEP and related neuromuscular training interventions have demonstrated improvements in hip and knee mechanics, dynamic knee valgus, landing control, and postural stability, including in athletes following ACL reconstruction. These findings indicate that PEP may serve as a useful adjunct to ACL rehabilitation and second-injury prevention by addressing modifiable neuromuscular and biomechanical risk factors. However, direct evidence specifically examining dynamic knee alignment and neuromuscular control following ACL rehabilitation in football players remains limited. Further well-designed randomized controlled trials with larger post-ACLR populations, standardized PEP protocols, and longer follow-up are needed to establish its effectiveness in reducing ACL re-injury and facilitating safe return to football.

DECLARATIONS

Study Limitations

The present narrative review has several limitations. Considerable heterogeneity existed among studies regarding participant characteristics, ACL reconstruction status, rehabilitation stage, intervention protocols, and outcome measures, limiting direct comparisons. Although the

review focused on the PEP program, some studies evaluated related neuromuscular, proprioceptive, or injury-prevention interventions, providing indirect rather than direct evidence. Differences in biomechanical and functional assessment methods further limited synthesis. Additionally, several studies assessed acute effects, whereas others examined longer-term training adaptations. Evidence specifically involving football players following ACL reconstruction remains limited. Finally, quantitative pooling of results was not performed because of the narrative design. Further standardized trials are warranted.

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Competing Interests

The researcher confirm no competing interests relevant.

Reference

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