REVIEW OPEN ACCESS

Consensus Statements—Optimizing Performance of the Elite Athlete

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ABSTRACT

The International Consensus Conference "Optimising Performance of the Elite Athlete," held in November 2024, brought together 29 scientists, some coaches, and athletes to establish evidence-based consensus statements aimed at enhancing elite athletic performance and health. The conference addressed critical themes including training strategies, nutrition, female athlete considerations, injury management, and emerging technologies. Key conclusions emphasize individualized, sport-specific approaches to training and nutrition, integrating concurrent training modalities to improve endurance, resilience, and efficiency. Nutrition strategies highlight the importance of tailored energy and macronutrient periodization, recognition of low energy availability risks, and cautious use of dietary supplements. Special attention was directed to female athletes, advocating for improved monitoring of menstrual cycles and hormonal status, while acknowledging current knowledge gaps in hormonal influences on performance and injury risk. Injury prevention remains a challenge, with tendon overuse and Achilles tendon ruptures significantly impacting athlete careers; rehabilitation should rely on criteria-based progression and multidisciplinary input. Emerging technologies, including wearable sensors and multi-omics analyses, hold promise for personalized training and nutrition but require further validation in elite contexts. Despite robust consensus, the panel iden-tified substantial research gaps, particularly regarding female athletes, longitudinal training effects, and efficacy of novel interventions. This consensus provides a practical, scientifically grounded framework to optimize elite athlete performance

and health, while underscoring the need for continued research to address outstanding questions and promote inclusive evidence-based practices.

1 | Introduction

From the 4th to 7th of November 2024, the Department of Nutrition, Exercise, and Sports, University of Copenhagen and Team Denmark, hosted the International Consensus Conference "Optimising performance of the elite athlete". Twenty-nine leading scientists, together with some few top athletes and coaches attended the conference, which was financially supported by the Novo Nordisk Foundation and Team Denmark. The conference produced several evidence-based conclusions. These are presented as consensus statements, followed by identified research gaps and practical recommendations for elite athletes, coaches, and healthcare professionals to enhance performance and promote health. That said, many of the recommendations also apply to athletes aspiring to reach the top level. The consensus statements were developed from the available evidence-based science, both from the laboratory and real-world settings, and not based on dogma. However, it is acknowledged that the evidence available on elite athletes is spare and will likely remain difficult to study due to the limited accessibility and numbers of such individuals who can participate in research [1]. These points highlight the improbability of future research employing the most rigorous original study designs, such as randomized controlled trials, which are essential for establishing definitive cause-and-effect relationships [2]. It is important to acknowledge that most available evidence is based on males, highlighting the need for more research on female athletes, particularly in topics wherein between-sex differences of athletes influence training adaptations and performance outcomes.

The conference sought to evolve evidence-based statements and recommendations to aid the elite athlete and build upon prior well-established principles from leading sports agencies (e.g., the International Olympic Committee) [3–5]. The themes covered were "Training strategies to optimise performance", "Nutrition strategies for performance augmentation in athletes", "The female athlete", "Load, injuries and return-to-competition", and "New technologies". The publication of these statements will be followed by a special issue of the *Scandinavian Journal of Medicine and Science in Sports*, where reviews [6–14] provide an in-depth understanding of the topics presented in the consensus statements.

In framing the statements, the panel prioritized human-focused research. Sex-specific factors were only addressed when there was a strong mechanistic rationale to justify their inclusion.

Overarching themes from the conference deliberations were how critical it is for elite athletes to:

- "train and test for the demands of their sport",
- "fuel for the demands of their sport",
- "recognize and implement an individualized approach",
- "understand the importance of education as a primary tool to facilitate trainability, performance and athlete health".

The panel consisted of clinicians, sports scientists, coaches, athletes, and practitioners from around the world, with a broad spectrum of expertise grounded in their experiences, scientific research, and well-acknowledged contributions to the understanding of human performance and health in athletes. The consensus was based on full agreement among all the participants and obtained through an iterative process that began with presentations of the state-of-the-art in each domain, followed by plenary and group discussions. Ultimately, consensus conference participants reached agreement on the 19 items within the consensus statements. Each statement was discussed in detail, and once consensus was reached, its practical application was explored, followed by an identification of areas requiring further research.

A key goal of the panel was to convey information in clear, concise, and practical language. Nonetheless, throughout this document, and specifically within the consensus statements themselves, some technical terminology and language are utilized. As such, a table of operational definitions (see Table 1) is provided to aid the reader so a complete understanding of meaning can be conveyed.

2 | Training Strategies to Optimize Performance

2.1 | Statement 1

The primary determinants of endurance performance are maximum oxygen uptake ($\dot{V}O_2$ max), a sustainable fraction of VO_2 max for a given distance, and movement efficiency or economy [7]. These factors operate together to establish the speed that can be maintained at a given oxygen uptake ($\dot{V}O_2$). In addition, there is an anaerobic energy component that contributes to performance, particularly in a sprint finish [15].

2.1.1 | Recommendations

To optimize the above factors, contemporary training approaches should incorporate a sufficiently high volume of moderate-intensity training, and in particular, targeted heavy to severe intensity interval training that exceeds race pace (e.g., speed endurance training and speed training).

2.1.2 | Need for Further Research

While many studies examine these outcomes in sub-elite or aspiring athletes, data on top-tier athletes, particularly

TABLE 1 | Operational definitions of select terms and language utilized.

Term/Phrase	Definition
Adaptive low energy availability (LEA)	Exposure to a short-term reduction in energy availability that is associated with mild and quickly reversible changes in body systems with minimal (or no) impact on long-term health, well-being, or performance.
Aerobic high-intensity training	Training that comprises intervals with a duration from 15-s up to 8 min, usually in a 1:1 or 2:1 work: rest ratio, at an intensity where the heart rate reaches > 90% of maximum.
Body composition	Describes and quantifies various elements, e.g., fat mass and muscle mass, within the human body.
Concurrent training	Training referring to programmes that in the same session or on the same day combine various training modalities, e.g., aerobic, anaerobic, and resistance (strength) training.
Iron sauce profiling	Profiling of iron status based on select biomarkers in blood, including transferrin saturation, ferritin, and hemoglobin.
Low Energy Availability (LEA)	Inadequate energy to support the functions required by the body to maintain optimal health and performance. Occurs as a continuum between scenarios in which effects are benign (Adaptive LEA) and others in which there are substantial and potentially long-term impairments of health and performance (problematic LEA).
Menstrual Cycle Symptoms	Physical, emotional, and behavioral changes that women either perceive or experience during the different phases of the menstrual cycle. Symptoms vary widely between individuals and can change throughout a person's reproductive years. They are most commonly associated with premenstrual syndrome (PMS) and premenstrual dysphoric disorder (PMDD), but they can also occur during ovulation or menstruation.
Menstrual Cycle Tracking	Monitoring and recording various aspects of the menstrual cycle over time. Typically involves tracking dates of menstruation and associated symptoms, as well as changes in physical, emotional, and behavioral patterns.
Multi-disciplinary team	Group of professionals from different disciplines who work together collaboratively to deliver comprehensive care or solutions.
Omics	Omics encompasses fields that study biological molecules on a large scale to understand the structure, function, and dynamics of living systems. Key areas include genomics (DNA), transcriptomics (RNA), proteomics (proteins), metabolomics (metabolites), and epigenomics (epigenetic modifications). Omics approaches are crucial for systems biology and for enabling applications in precision medicine, disease diagnosis, drug discovery, and evolutionary studies.
Problematic LEA	Persistent disruption of body systems due to exposure to LEA. Often presents with signs and symptoms and represents a maladaptive response. The characteristics of problematic LEA exposure (e.g., duration, magnitude, frequency) varies according to the individual.
Speed endurance training	Training that comprises repeated intense efforts (higher than that eliciting maximum oxygen uptake), typically lasting 20 s to 1 min, interspersed with recovery intervals of either short (maintenance training, 1:1–3 work: rest ratio) or long (production training, 1:5 work: rest ratio) duration.
Physiological profile	A physiological profile is a comprehensive assessment of an individual's physical and biological traits influencing health, fitness, and performance, which enables tailored interventions to optimize performance, reduce injury risks, and enhance recovery, supporting long-term athletic development and peak outcomes.

regarding longitudinal performance-limiting factors, are scarce.

2.2 | Statement 2

Physiological resilience (referred to as "durability" in some literature) has emerged as a fourth dimension contributing to endurance performance and refers to the capacity to withstand or recover from functional decline during a prolonged "single" exercise stress (i.e., a marathon or a 1-day classic in cycling). Resilient athletes more effectively maintain their sustainable fraction of $VO_{2\text{-max}}$ and movement economy during competition [7].

2.2.1 | Recommendations

Resilience should be considered an essential component in the performance optimization of endurance athletes by implementing appropriate training and nutrition strategies.

2.2.2 | Need for Further Research

Studies should optimize protocols to reliably assess physiolog-ical resilience across different athlete cohorts and explore the mechanisms that determine resilience to find the most effective ways to enhance resilience.

2.3 | Statement 3

Concurrent training strategies, such as incorporating resistance, speed endurance, speed, and plyometric training, are important to optimize endurance performance [7, 8, 16]. The effect includes enhancement of high-i ntensity parameters (e.g., starting and finishing sprints, surges) and movement economy or efficiency. Engaging in various training modalities on the same day does not diminish the effectiveness of each individual modality [17].

2.3.1 | Recommendations

Training paradigms for endurance athletes should consider the addition of resistance, speed endurance, speed, or plyomet-ric exercises routinely to enhance the above parameters. The combination of training modalities can be performed in several ways. Nevertheless, concurrent training prescriptions should be specified on an athlete- by- athlete basis to optimize individual performance based on factors such as training backgrounds, ex-perience, and tolerability.

2.3.2 | Need for Further Research

Future directions in the field should aim to determine optimized concurrent training paradigms for elite athletes.

3 | Nutrition Strategies for Performance Augmentation in Athletes

3.1 | Statement 4

The amount, composition, and timing of food and fluid intake impact the health and performance of athletes by altering fuel stores and utilization during training and competition, as well as influencing the incidence of illness and injury, time course of recovery, and magnitude of adaptation [18, 19]. Nutrition re-quirements for energy, macronutrients, fluids, and micronutri-ents supporting training, competition, and recovery are broadly understood and provide a foundation for developing tailored and individualized nutrition strategies [9, 18, 19].

3.1.1 | Recommendations

Athletes should engage with an appropriately qualified physi-ologist, sports dietitian, or nutritionist, either individually or within a multidisciplinary support team. An assessment of di-etary intake and nutrient status is an appropriate starting point, and could be supported by assessments of nutrition knowledge, capability, motivation, beliefs, preferences, and cultural fac-tors [20, 21]. Individualized plans that are aligned with general sports nutrition guidelines should consider contextual factors, including the athlete's physiological profile, training demands, seasonal objectives, and environmental challenges [21]. This holistic approach ensures appropriate recommendations for optimal energy availability and nutrient intake tailored to each athlete's unique circumstances. Athletes and coaches should be aware that low energy availability (LEA) may have adverse ef-fects on performance, injury risk, and health [11, 22] (see also Section 3.3 and Section 4.5).

3.1.2 | Need for Further Research

Nutrition strategies for augmenting performance in elite athletes are likely to be optimized if they are tailored to the demands of specific sports, to varying levels of intensity and volume of exercise training, and to the specific physiolog-ical profile of a given athlete [21]. There remain knowledge gaps in providing specific guidelines in many sports. The current understanding of the role of energy and nutrient in-takes during off- season training and recovery periods remains under-researched.

3.2 | Statement 5

Energy and macronutrient intakes can be periodised through targeted strategies that address the changing needs of the ath-lete attributed to different goals and demands within training sessions, blocks, and across the phases of a season (e.g., prepa-ration and competition) [21, 23]. A periodised approach to nu-trition can enhance the performance in, and adaptations to, individual exercise sessions or periodic training plans [21, 23].

3.2.1 | Recommendations

Athletes should scale the energy, carbohydrate, and fluid in-take before, during, and after training to the demands and in accordance with the purpose of the training phase concerned. Likewise, scaling the carbohydrate and fluid intake around competition to the demands and needs of competition is consid-ered a relevant aspect of performance optimization [24, 25]. The latter applies primarily to weight-bearing disciplines.

3.2.2 | Need for Further Research

The effects of long-term periodized macronutrient intake on health and performance should be examined.

3.3 | Statement 6

Weight loss induced by low energy availability does not always improve performance and may have negative effects on energy and protein metabolism, training adaptations, and performance [11, 26, 27].

3.3.1 | Recommendations

Athletes should follow an individualized and sports-specific approach for potential weight management supported by the multidisciplinary health and performance team including sports medicine, nutrition, psychology, and scientific personnel, for example, by using the 8-step best practice guidelines by Mathisen et al. [26].

3.3.2 | Need for Further Research

High-quality studies are needed to investigate the interaction between low energy and carbohydrate availability, the timing of nutrient intake in relation to training sessions, the impact of repeated periods of low energy availability, and the dose–response of energy availability levels and the duration of the LEA period on athlete' health, adaptation to training, and performance. Furthermore, more research is needed to elucidate the time frame and strategies needed for recovery after periods of low en-ergy availability, in respect to re-establishing optimal physical function.

3.4 | Statement 7

There is widespread interest from athletes in the use of diteary supplements. These supplements can be used to prevent declines in health or performance in the case of addressing a nutrient de-ficiency, or as a specific ergogenic aid to improve performance, but few dietary supplements have been consistently demon-strated to be effective as an ergogenic aid [28, 29].

3.4.1 | Recommendations

A thorough risk–benefit analysis is essential, weighing the potential advantages against the risks to health, performance, reputation, and risk of a negative doping test due to illegal substances added on purpose or through contamination in production [30]. Deficiencies should be objectively assessed and addressed by a qualified practitioner [20]. The selection and use of ergogenic aids should be evidence-based and in line with published guide-lines on safety and efficacy, including anti-doping violations [28]. The readers can refer to the extensive list of potentially relevant supplements listed in a recent IOC statement [28] with supplements such as creatine and caffeine having a strong evi-dence base to improve performance [31–35], although more re-cent meta-analysis data do not support the benefit of nitrate in elite endurance athletes [36].

3.4.2 | Need for Further Research

The combined or interactive effects of the use of dietary supplements are currently not well described. Whether the recommended dosing of supplements from existing research can differ when applied to elite athletes across different sports is unknown.

3.5 | Statement 8

While there is a large body of evidence in the domain of sports nutrition, there is a scarcity of field-based studies on elite athletes, and it is unlikely that randomized controlled trials can be performed on adequate numbers of elite athletes [37].

3.5.1 | Recommendations

Athletes and coaches should prioritize nutrition strategies tested in both laboratory- and field-based settings when available. Established nutrition strategies should serve as starting points, but individualized trial-and-error approaches should be employed to optimize responses for the individual athlete based on tolerability, acceptability, and benefit to health and performance [9, 37]. In doing so, athletes may ensure that strategies are feasible and effective in practice ahead of competition.

3.5.2 | Need for Further Research

There is a need for rigorous field-based data collection with strong ecological validity to evaluate laboratory-based findings for translation into real-world scenarios, which may also include well-controlled case studies of elite athletes in training and competition.

4 | The Female Athlete

4.1 | Statement 9

Monitoring menstrual cycles, hormonal contraceptive use, and other relevant ovarian hormone events (e.g., menopause and pregnancy) is recommended for elite female athletes. Ovarian hormone profiles must be established using valid methodological approaches as described by Janse de Jonge et al. [38] or Elliott-Sale et al. [39].

4.1.1 | Recommendations

Currently available menstrual cycle tracking apps to determine menstrual cycle phases for guiding training, performance, or nutrition decisions are not evidence-based and are not recommended for use. Use instead subjective, for example, own experiences, and objective measurements, such as blood samples or clinical assessment, to establish menstrual cycle phases.

4.1.2 | Need for Further Research

Development of objective biological-based and validated monitoring and tracking options for female athletes is warranted. Such development should involve research in both laboratory and field-based settings.

4.2 | Statement 10

To date, there is insufficient high-quality evidence to show if and how menstrual cycle hormonal fluctuations influence training adaptations, phase-based nutrition recommendations, athletic performance, or injury risk [40]. However, for some female athletes, menstrual cycle symptoms may influence their perceived or actual ability to exercise train, fuel, recover, or perform athletically [41].

4.2.1 | Recommendations

Female athletes should take an individual approach and communicate any impactful menstrual cycle symptoms to an appropriate medical professional for diagnosis and treatment, and other relevant sports personnel for consideration relative to modifications in training and competition.

4.2.2 | Need for Further Research

Future studies should focus on how best to identify and treat menstrual cycle symptoms. In addition, further high-quality studies should be conducted on the effects of fluctuations in ovarian hormones across menstrual cycles. Individual data should be presented and considered rather than only group, mean responses.

4.3 | Statement 11

The effects of hormonal contraception vary depending on generation, type, and dose. At present, there is insufficient high-quality evidence from randomized controlled trials to show if and how hormonal contraception influences athletic performance, muscle recovery or strength, cardiovascular function, adaptations to exercise training, and injury risk [42, 43].

4.3.1 | Recommendations

Hormonal contraceptive use should be discussed in the first instance with an appropriate medical professional. Until more evidence is available, the use of hormonal contraception should be considered in relation to birth control and other evidence-based medical considerations, rather than in relation to aspects related to sports performance.

4.3.2 | Need for Further Research

Future studies must consider the specific generation, type, and dose of hormonal contraception employed within the study. In addition, high-quality studies should focus on the physiological and psychological responses to the use of hormonal contraceptives.

4.4 | Statement 12

Female athletes should be aware that heavy menstrual bleeding, restricted or vegan diets, and high training volume increase the risk of iron deficiency, with or without anemia, with potential implications for health and performance [44, 45].

4.4.1 | Recommendations

Profiling iron status using key blood biomarkers, including transferrin saturation, ferritin, and hemoglobin, should be undertaken at least once a year following best practice guidelines [46], in addition to real-time communication with the sports personnel about factors affecting iron status, such as altitude training, major dietary changes, or disordered eating behavior.

4.4.2 | Need for Further Research

Optimal supplementation practices and dosing protocols for female athletes to prevent and treat iron deficiency need to be further explored.

4.5 | Statement 13

Female athletes and coaches should be specifically aware that problematic LEA may have adverse effects on performance, in-jury risk, and health [47, 48].

4.5.1 | Recommendations

Athletes, coaches, and the health-performance team must be vigilant for signs and symptoms of problematic LEA, such as lack of training adaptation, irregular or loss of menstruation, and disordered eating behavior.

4.5.2 | Need for Further Research

More research is needed to develop and evaluate effective pre-vention initiatives and treatment plans to elucidate the time frame and strategies needed for recovery of signs and symptoms of problematic LEA in female athletes.

5 | Load, Injuries and Return-To-Competition

5.1 | Statement 14

Injuries in elite athletes are frequent and despite efforts to avoid these through prevention programs, no marked reduction in the numbers of injuries can be observed over the last 15+ years [49, 50]. Even though there is a high number of acute injuries, the number of overuse injuries also represents a substantial burden on the athletes.

5.1.1 | Recommendations

Establishing national registration of sports-specific injuries in elite athletes and the causes thereof should be encouraged.

Elite sports organizations should facilitate an injury registration set-up for early detection and intervention of injury, illness, and mental health issues.

5.1.2 | Need for Further Research

Despite evidence- based documentation of injury- preventive interventions, there is limited knowledge on the degree of true implementation and elite-a thlete compliance to these interventions.

5.2 | Statement 15

Tendon overuse injuries can be long-l asting (years) and a frequent reason for the termination of athletic careers [51]. Subjective feelings of tendon stiffness, palpatory soreness, and swelling of the tendon are early phenomena for tendon overuse in both recreational and elite athletes. The shorter the duration of the tendon overuse injury has lasted, the faster the pain-free return to sport.

5.2.1 | Recommendations

Early signs of tendon overuse injury should be taken seriously and should result in an overall lowering of the training volume with a special focus on reducing the loading of the specific tendon.

5.2.2 | Need for Further Research

The scientific community lacks the ability to determine early tendon changes that can be used to monitor how much train-ing the athlete can tolerate to perform without worsening of the overuse injury. It is unknown what magnitude of loading can be tolerated during rehabilitation of tendon overuse injury, and a test to support the decision on return to full participation in sports should be developed.

5.3 | Statement 16

Rupture of the Achilles tendon causes a significant number of elite athletes to fail to return to their prior level [52, 53]. Healing of the Achilles tendon requires substantial time (~1 year) and a long period without participating in the specific sport [54]. Current treatment of Achilles tendon rupture has demonstrated that both surgical and non- surgical treatment leads to elonga-tion of the tendon, a permanent shortening, loss of muscle vol-ume, weakening of the triceps surae muscle, and an incomplete return of function.

5.3.1 | Recommendations

Efforts should be undertaken to avoid undue Achilles tendon elongation in the early phase of rehabilitation.

5.3.2 | Need for Further Research

Different surgical treatment techniques and rehabilitation pro-grams should be investigated to avoid tendon elongation, loss of muscle volume, and to improve the return of full function.

5.4 | Statement 17

The rehabilitation process is dependent upon criteria- based rather than time- based progression. Several tests and factors have been shown to correlate with a successful return to sport, but despite efforts to identify factors that can predict return to sport, no specific factors or tests can stand alone in the decision- making on return to sport [13, 55].

5.4.1 | Recommendations

The decision on when to return to sports for the elite athlete is a shared decision between the athlete, the clinicians, and the coach. This includes the use of clinical tests, para-clinical objec-tive measures, and sports-specific tests.

5.4.2 | Need for Further Research

Specific clinical and sport- specific field tests to predict the time to return to sport, as well as the risk of re-i njury, are lacking. The tests should consider the characteristics and fatigability of the specific sport and relate to baseline testing.

5.5 | New Technologies

5.5.1 | Statement 18

New technologies can be exploited to uncover subtleties pertain-ing to athletic performance. Integrating DNA, RNA, protein, and metabolite data (e.g., omics and artificial intelligence (AI)) [56–60] with physiological measures may reveal drivers of ath-letic phenotypes and enable the optimization of performance, training, and recovery strategies [14, 61, 62].

5.5.2 | Recommendations

Inter- disciplinary efforts should be encouraged to collect, store, and analyze biological samples (e.g., saliva, urine, sweat, and feces) that are practically obtainable in athletes under various controlled conditions to facilitate the discovery of potential biomarkers of fa-tigue, overreaching, stress, performance level, and health.

5.5.3 | Need for Further Research

While omics and AI continue to advance the biomedical re-search field, their potential utility remains to be established within sport contexts.

5.6 | Statement 19

Technological innovations are likely to enable the development of personalized training and nutrition strategies in the next decades through emerging technologies. Examples include utilizing wearable sensors and real-time monitoring to enable precise measurement of individual responses in the field and utilizing multi-omics approaches. Combined, these innovations may allow for better tailoring of training and nutrition strategies across the varying demands of training and competition [9].

5.6.1 | Recommendations

Intra- and inter-individual variations in response to nutrition and exercise training interventions are well established but are yet to be translated into actionable strategies for athletes. Advancements in innovative technologies may be used to develop personalized training and nutrition strategies, while recognizing that much of this field is in its infancy.

5.6.2 | Need for Further Research

A shift towards personalized training and nutrition could improve the health and performance of athletes, though the impact remains to be fully measured. New wearables and affordable omics technologies will require validation through traditional laboratory-based experimentation, as well as being supported by bioinformatics and AI to incorporate the processing and interpretation of big data.

6 | Perspectives

Key recommendations from the consensus conference emphasized the importance of tailored training strategies to optimize endurance, resilience, and performance efficiency through balanced and specialized exercise regimens. Nutrition guidance stressed individualized dietary plans aligned with athletic demands, while addressing challenges like low energy availability and dietary supplement risks. Special attention was given to female athletes, calling for improved menstrual cycle tracking, hormonal impact research, and protocols for addressing iron deficiency. The conference also underscored injury prevention and rehabilitation, advocating for early detection, individualized care, and collaborative decision-making for return-to-sport protocols. Despite advancements, gaps remain in understanding injury mechanisms and effective interventions. Technological innovations such as wearable sensors and "omics" technologies were discussed as potential tools to personalize training, nutrition, performance, and recovery. However, further research is needed to validate these approaches in real-world elite settings. Overall, the conference provided a comprehensive roadmap for optimizing elite athlete health and performance, with a call for more inclusive, high-quality research, particularly on female athletes, and longitudinal training effects.

Author Contributions

All authors contributed equally to the manuscript and have approved the final version.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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