QUALITY IN SPORT
eISSN 2450-3118 · Open Access · Peer-reviewed
apcz.umk.pl/QS Nicolaus Copernicus University in Toruń

CZAJKA, Alicja, BANAŚ, Anna, CIESIELCZYK, Jan, CZARNACKI, Dawid, CIĘSZCZYK, Angelika, MŁYNARCZYK, Magdalena, CARUK, Jan, ŚLICZNIAK, Iga, SZKUP, Paweł and LUKOVYCH, Kvitoslava. Hematuria, proteinuria, and albuminuria following exercise in athletes: mechanisms, time course, renal biomarkers, and diagnostic approach - a narrative review. Quality in Sport. 2026;76:76042. https://doi.org/10.12775/QS.2026.76.76042

ARTICLE TIMELINE
Received: 12.09.2026. Accepted: 17.09.2026. Published: 24.09.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).
Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych).

Hematuria, proteinuria, and albuminuria following exercise in athletes: mechanisms, time course, renal biomarkers, and diagnostic approach - a narrative review.

Alicja Czajka

ORCID: https://orcid.org/0009-0005-8774-4743

alaczajka2003@gmail.com

Medical University of Lublin

Aleje Racławickie 1; 20-059 Lublin; Poland

Anna Banaś

ORCID: https://orcid.org/0009-0006-3227-7428

annabanas05@gmail.com

Medical University of Lublin

Aleje Racławickie 1; 20-059 Lublin, Poland

Jan Ciesielczyk
ORCID: https://orcid.org/0009-0007-5919-7804
jancie.photo@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Dawid Czarnacki
ORCID: https://orcid.org/0009-0000-6403-0223
dawidchabrowaa@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Angelika Cięszczyk
ORCID: https://orcid.org/0009-0006-7011-3088
angelikacieszczyk87@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Magdalena Młynarczyk
ORCID: https://orcid.org/0009-0003-4151-661X
magdamlynarczyk10@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Jan Caruk
ORCID: https://orcid.org/0009-0000-3823-6885
jancaruk@interia.pl
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Iga Śliczniak
ORCID: https://orcid.org/0009-0006-5362-5161
iga.sliczniak@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Paweł Szkup
ORCID: https://orcid.org/0009-0007-9981-5080
pawelszkup22@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Kvitoslava Lukovych
ORCID: https://orcid.org/0009-0005-4906-1167
kvitkalukovych@gmail.com
Medical University of Lublin
Aleje Racławickie 1; 20-059 Lublin, Poland

Corresponding Author: Alicja Czajka, alaczajka2003@gmail.com

Abstract

Background: Hematuria, proteinuria, and albuminuria may occur transiently after intense or prolonged exercise, complicating differentiation between a post-exercise response and kidney or urinary tract disease.

Aim: To summarize the mechanisms, time course, renal biomarkers, and features that help distinguish transient post-exercise abnormalities from findings requiring further evaluation.

Material and methods: A structured narrative review was conducted using PubMed. Publications from 2021–2026 were prioritized; 27 publications were included.

Results: Exertional hematuria may be renal or mechanical in origin, whereas post-exercise proteinuria may have glomerular and tubular components. The pattern of changes is influenced by exercise duration and hydration status, whereas interpretation also depends on sample collection timing. Creatinine requires cautious interpretation after intense exercise because muscle metabolism and injury may increase its concentration. Cystatin C may complement renal function assessment. uKIM-1 and uNGAL may provide information on tubular injury, but variable post-exercise responses and lack of standardized cutoff values limit interpretation.

Conclusions: Post-exercise abnormalities should be interpreted in clinical and temporal context. Persistent or recurrent abnormalities, features suggestive of a glomerular origin of hematuria, impaired renal function, or symptoms of rhabdomyolysis warrant further diagnostic evaluation.

Keywords: hematuria; proteinuria; albuminuria; physical exercise; athletes; renal biomarkers; KIM-1; NGAL

1. Introduction

1.1. Definitions and Clinical Significance

Hematuria refers to the presence of red blood cells in the urine and can be macroscopic or microscopic [1]. According to the AUA/SUFU guidelines, microhematuria is diagnosed when at least 3 red blood cells per high-power field are identified on microscopic examination of a properly collected sample [2]. A positive dipstick test alone is insufficient to establish the diagnosis of microhematuria and should be followed by microscopic examination of the urine [2]. Exertional hematuria refers to the painless presence of red blood cells in the urine following recent physical exercise, not directly related to external trauma to the genitourinary tract, and usually resolves spontaneously with rest [1].

Proteinuria refers to increased urinary protein excretion, whereas albuminuria refers specifically to increased urinary albumin excretion [3]. In a spot urine sample, albuminuria is assessed using the urinary albumin-to-creatinine ratio (ACR), whereas total protein excretion is assessed using the urinary protein-to-creatinine ratio (PCR) [3].

Interpretation of these measures requires consideration of biological factors affecting the excretion of albumin, protein, and creatinine, including recent physical exercise and differences in creatinine excretion related, among other factors, to body mass and sex [3]. A positive dipstick result for blood may also occur in the presence of myoglobinuria or hemoglobinuria. Therefore, microscopic confirmation of red blood cells in the urine sediment is of key diagnostic importance [1,2].

1.2. Renal Response to Exercise and Rationale for the Review

Physical exercise induces a range of transient changes in renal function [4]. As exercise intensity increases, renal plasma flow decreases, changes in glomerular filtration occur, and hormonal mechanisms involved in sodium and water retention are activated [4]. The renal response to exercise is influenced by exercise intensity and duration, environmental conditions, and hydration status [4]. Dehydration, exposure to high temperatures, and rhabdomyolysis may further increase the risk of renal dysfunction associated with intense or prolonged exercise [4,5].

Following intense exercise, urinalysis may reveal abnormalities including hematuria, proteinuria, and albuminuria [1,4,6]. Post-exercise changes may also be accompanied by increases in biomarkers associated with renal stress or injury, including urinary kidney injury molecule-1 (uKIM-1) and urinary neutrophil gelatinase-associated lipocalin (uNGAL) [7].

Since some of these changes are transient, their interpretation requires consideration of the exercise context and the timing of sample collection [1,4].

The available literature includes separate studies on exercise-induced hematuria, proteinuria, acute kidney injury, and selected renal biomarkers [1,5,6,7]. Therefore, an integrated discussion of the mechanisms underlying these changes, their time course, and the parameters that may help distinguish a transient post-exercise response from abnormalities requiring further diagnostic evaluation is warranted.

1.3. Aim of the Review

The aim of this narrative review is to summarize the current state of knowledge regarding hematuria, proteinuria, and albuminuria occurring after physical exercise in athletes, with particular emphasis on their underlying mechanisms, time course, and the significance of selected renal biomarkers. The review also aims to identify features that may help distinguish a transient post-exercise response from abnormalities requiring further diagnostic evaluation.

2. Materials and Methods

This study was conducted as a structured narrative review focusing on hematuria, proteinuria, and albuminuria occurring after physical exercise, as well as on the interpretation of changes in markers of renal function and kidney injury in athletes. The literature search was conducted in the PubMed database, with the final update performed on September 7, 2026. The search was iterative and used combinations of terms related to the main areas of the review, including hematuria, proteinuria, albuminuria, exercise, athletes, renal biomarkers, KIM-1, NGAL, cystatin C, creatinine, rhabdomyolysis, marathon, ultramarathon, and urinalysis.

Publications from 2021–2026 were prioritized. Older studies were included only when they directly addressed the mechanisms under review, the time course of post-exercise changes, or provided clinically relevant data that were insufficiently represented in more recent literature. Eligible publications included original studies involving human participants, systematic and narrative reviews, meta-analyses, current clinical guidelines, consensus documents, and selected case series directly relevant to the topic. Studies involving athletes and physically active individuals were prioritized. Publications concerning the general population were included when they were relevant to the interpretation of hematuria, albuminuria, urine microscopy, or further diagnostic evaluation.

Publications not directly related to the renal response to exercise or post-exercise urinary abnormalities, animal studies, non-peer-reviewed reports, and sources whose content did not allow reliable assessment of the issues under review were excluded. The evidence was synthesized qualitatively, with particular attention to the type of exercise, timing of sample collection, hydration status, biomarkers assessed, and the clinical significance of the observed changes. No meta-analysis or formal risk-of-bias assessment was performed.

The final synthesis comprised 27 publications: 24 published between 2021 and 2026 and three older publications from 2019–2020, retained because of their direct relevance to the topics addressed in this review.

3. Mechanisms and Time Course of Post-Exercise Changes

3.1. Mechanisms of Exertional Hematuria

Hematuria occurring after exercise may arise from both renal mechanisms and mechanical injury to the urinary tract [1]. Potential renal mechanisms include renal vasoconstriction, transient ischemia, and increased permeability of the glomerular filtration barrier to red blood cells [1].

An extraglomerular mechanism may result from mechanical trauma to the bladder mucosa [8]. In the study by Urakami et al., which included 12 patients presenting with macroscopic hematuria after running, cystoscopy revealed contusions in the central portion of the posterior bladder wall in 9 patients [8]. The authors attributed these lesions to repeated contact between the posterior bladder wall and the fixed bladder neck during vertical movements when the bladder was nearly empty [8]. Macroscopic hematuria resolved without treatment in all patients after cessation of running [8].

3.2. Mechanisms of Post-Exercise Proteinuria and Albuminuria

Post-exercise proteinuria may involve both glomerular and tubular components [4]. During intense exercise, the reduction in renal plasma flow is greater than the reduction in glomerular filtration rate [4]. This is accompanied by an increase in the filtration fraction and increased permeability of the glomerular filtration barrier [4]. These changes facilitate the passage of albumin into the glomerular filtrate and may contribute to post-exercise albuminuria [4].

At the same time, the accumulation of metabolic byproducts during exercise may disrupt the electrochemical gradient in the renal tubules and impair the reabsorption of low-molecular-weight proteins [4]. Consequently, post-exercise proteinuria may have a mixed glomerular and tubular pattern [4].

The importance of exercise duration is demonstrated by data from marathon and ultramarathon races. In a study including 20 marathon participants and 17 participants in a 100-km race, ACR increased from 6.41 to 21.96 mg/g after the marathon and from 5.37 to 49.64 mg/g after the ultramarathon [6]. The increase was greater after the 100-km race, although no correlation was observed between ACR and running pace [6]. The authors suggested that, during very prolonged exercise, the magnitude of post-exercise albuminuria may be more closely related to exercise duration than to exercise intensity [6].

More recent data also show that both urinary albumin and total protein excretion may increase following ultra-endurance exercise [9]. In a study of 20 men who completed a 100-km cross-country ultramarathon, urinary albumin and total protein concentrations, as well as ACR and PCR, increased significantly immediately after the race [9]. No correlation was found between running speed and changes in ACR or PCR [9]. In the context of the mechanisms described above [4], the simultaneous increase in ACR and PCR observed after exercise [9] may reflect the coexistence of increased glomerular permeability and altered tubular handling of filtered proteins.

3.3. Time Course and Modifying Factors

The observed pattern of post-exercise changes in renal parameters is heterogeneous and depends, among other factors, on exercise duration and hydration status, while interpretation is also influenced by the timing of sample collection [4,7,10,11]. Studies of marathon and ultramarathon runners have demonstrated increases in albuminuria and proteinuria immediately after exercise [6,9].

Serial measurements of renal biomarkers indicate that individual parameters may exhibit different time courses during the post-exercise period [7,11,12]. In a study of high-intensity intermittent running, uNGAL did not differ from baseline after 24 hours, whereas uKIM-1 remained elevated under conditions of hypohydration [7]. In a study of prolonged cycling in the heat, hypohydration was associated with a greater response of selected tubular biomarkers even after accounting for urine concentration, particularly 30 minutes after exercise [11]. In a field study following a 100-mile ultramarathon, completing the race in an euhydrated state was associated with a smaller increase in some of the assessed renal biomarkers [13].

During repeated training sessions, changes in different biomarkers do not necessarily occur in parallel [14]. Evidence regarding the effect of non-steroidal anti-inflammatory drug (NSAID) use on the risk of exercise-associated kidney injury remains inconclusive [15,16].

4. Laboratory Assessment and Interpretation of Renal Parameters

4.1. Urinalysis, Urine Microscopy, and ACR/PCR

Urinalysis together with microscopic examination of the urine sediment forms the basis for the evaluation of hematuria [2]. A positive dipstick result for blood should be verified by microscopic examination confirming the presence of red blood cells in the urine [2].

Assessment of red blood cell morphology may further assist in determining the source of hematuria [17,18]. The presence of dysmorphic red blood cells, particularly acanthocytes, and red blood cell casts suggests a glomerular origin [17]. The utility of red blood cell morphology in differentiating glomerular from non-glomerular hematuria is also supported by more recent multicenter data [18].

Quantitative methods are preferred for the assessment of albuminuria and proteinuria [3]. According to the KDIGO guidelines, albuminuria is assessed using the urinary albumin-to-creatinine ratio (ACR), whereas the urinary protein-to-creatinine ratio (PCR) may be used to assess total urinary protein excretion [3]. When interpreting ACR and PCR in athletes, recent physical exercise should be taken into account because it may transiently increase urinary albumin and protein excretion and affect the values of both ratios [3].

4.2. Creatinine, Cystatin C, and Novel Renal Biomarkers

Serum creatinine remains a primary marker used to assess renal function, although its interpretation immediately after intense exercise is limited [4,5]. An increase in its concentration may result not only from reduced glomerular filtration but also from increased creatinine production associated with muscle metabolism and muscle injury [4,5]. Consequently, creatinine-based criteria for acute kidney injury (AKI) may overestimate the incidence of AKI in athletes following endurance exercise [4,5].

Cystatin C is an alternative filtration marker that is less dependent on muscle mass and diet than creatinine [5]. In a study of marathon runners with exertional heat illness, cystatin C concentrations were significantly higher than in runners who completed the same marathon without this complication [19]. However, findings from studies of marathon runners assessing cystatin C and other renal biomarkers are heterogeneous, making it difficult to define a typical post-exercise response [20].

Biomarkers of tubular injury include uKIM-1 and uNGAL [5]. Individual biomarkers may exhibit different responses to exercise [20,21,22]. In a study of seven ultramarathon runners following a 100-km race, serum NGAL (sNGAL) increased, whereas no significant change in urinary NGAL (uNGAL) was observed [21]. In contrast, in a study comparing high-intensity intermittent exercise with moderate-intensity continuous exercise, creatinine-adjusted uNGAL increased 60 minutes after exercise despite the absence of significant changes in renal blood flow [22]. Other potential biomarkers, including TIMP-2, IGFBP7, L-FABP, and MCP-1, have also been evaluated in marathon runners [20]. A more recent review suggests that novel biomarkers may provide additional information on the time course, severity, and localization of renal changes associated with intense exercise [23].

However, the practical use of novel biomarkers in the assessment of athletes remains limited [5,20]. The lack of standardized cutoff values for these biomarkers in the post-exercise setting, together with substantial between-study variability in biomarker responses, makes their interpretation challenging [5,20].

4.3. Limitations in the Interpretation of Results

Interpretation of renal parameters after exercise requires consideration of the conditions under which testing was performed. For urinary biomarkers, hydration status and urine concentration are particularly important [7,11,24]. Adjustment of biomarker concentrations for urine osmolality or creatinine may affect the interpretation of observed changes [7,11,24]. Hypohydration may also augment the response of some biomarkers even after accounting for the effect of urine concentration [7,11].

Comparison of results across studies is complicated by substantial methodological heterogeneity, including differences in participant characteristics, hydration status, environmental conditions, and study protocols [20].

5. Clinical Significance and Diagnostic Approach

5.1. Features Suggesting a Transient Post-Exercise Response

Exertional hematuria is typically painless, occurs after recent physical activity, and usually resolves spontaneously with rest [1]. Exercise may also transiently increase urinary albumin and protein excretion and affect ACR and PCR values [3]. Therefore, a single result obtained immediately after exercise should be interpreted in the context of recent physical activity, which may affect its value [3].

5.2. Warning Signs and Differential Diagnosis

Hematuria persisting for more than 72 hours after cessation of exercise, or recurrent hematuria, should prompt evaluation for other causes [1]. In cases of albuminuria or proteinuria, an abnormal result should be confirmed quantitatively, preferably using a first-morning urine sample, while taking recent exercise into account as a factor that may influence the result [3].

The presence of proteinuria, dysmorphic red blood cells, particularly acanthocytes, red blood cell casts, or impaired renal function should prompt nephrologic evaluation [2,17]. Dysmorphic red blood cells and red blood cell casts have high specificity for a glomerular origin of hematuria, although their sensitivity is variable [17]. The differential diagnosis should also include urologic causes, including urinary tract infection and urolithiasis, and further urologic evaluation should be guided by the clinical presentation and risk profile [2].

Severe muscle pain or swelling, weakness, and dark urine after exercise should raise suspicion of exertional rhabdomyolysis [25,26]. Measurement of creatine kinase (CK) and assessment of renal function, including serum creatinine, are key components of its evaluation [25,26].

5.3. Practical Diagnostic Approach and Implications for Physical Activity

In an athlete with an abnormal post-exercise urinalysis result, evaluation should begin by confirming the nature of the abnormality [2,3]. A positive dipstick test for blood should be followed by urine microscopy to confirm the presence of red blood cells [2]. If hematuria is detected after recent exercise, its temporal relationship to physical activity should be considered, and urinalysis should be repeated in the following days [1]. In cases of albuminuria or proteinuria, quantitative assessment using ACR or PCR should be performed, and an abnormal result should be confirmed in a subsequent sample, preferably a first-morning urine sample [3].

If the abnormality persists in the follow-up test, the scope of further diagnostic evaluation should be guided by urine sediment findings, the presence of proteinuria, renal function, and clinical symptoms [2,17]. In cases of rhabdomyolysis, return to physical activity should be gradual. Return to the usual level of activity should be deferred until pain has resolved and CK levels have returned to baseline; in the presence of concomitant kidney injury, normalization of kidney function should also be considered [25].

6. Discussion

6.1. Key Findings

A key finding emerging from the available evidence is that post-exercise abnormalities in urinalysis and renal parameters should not be interpreted on the basis of a single measurement without considering the exercise context [1,4,7,11]. Exertional hematuria may have either a renal or mechanical origin [1,8], whereas post-exercise proteinuria may have a mixed glomerular-tubular pattern [4]. The renal response is also influenced by exercise conditions and hydration status, and individual biomarkers may exhibit different temporal patterns [4,7,11].

The findings of this review also highlight the limitations associated with the interpretation of individual markers. Creatinine concentrations may be influenced by muscle metabolism and muscle injury [4,5], while the lack of standardized cutoff values currently limits the clinical use of novel biomarkers [5,20]. Transient post-exercise increases in creatinine, albuminuria, or tubular injury biomarker concentrations should therefore not be interpreted independently of the timing of sample collection and the clinical course [3,4,5]. At the same time, the transient nature of these changes does not preclude the need for further evaluation when abnormalities persist, worsen, or coexist with other features of kidney injury [1,2,3]. In practice, urine sediment microscopy, quantitative assessment of albuminuria and proteinuria, and assessment of renal function remain fundamental [2,3,17].

6.2. Strengths, Limitations, and Directions for Future Research

A strength of this review is its integrated presentation of post-exercise hematuria, proteinuria, and albuminuria, together with their interpretation using conventional and novel renal biomarkers. The inclusion of current guidelines and studies addressing different forms of exercise also supports a practical approach to the evaluation of abnormal findings in athletes.

However, the available studies are characterized by substantial heterogeneity, including differences in participant characteristics, exercise protocols, hydration status, environmental conditions, and timing of sample collection [20,27]. Some studies were conducted in small and specific participant groups, limiting the generalizability of their findings [7,9,11]. Another limitation is the lack of standardized cutoff values for novel post-exercise biomarkers [4].

Due to the narrative nature of this review, the findings of individual studies were synthesized qualitatively, without quantitative pooling. In addition, the literature search was conducted exclusively in PubMed, which may have resulted in the omission of some publications indexed in other bibliographic databases. Furthermore, no formal assessment of the methodological quality or risk of bias of the included studies was performed, which limits the ability to assess the strength of the available evidence.

Future studies should use more standardized protocols, particularly with regard to the timing of sample collection, methods used to assess hydration status, and the characteristics of the study populations [20,27]. Further studies are also needed to assess the long-term significance of recurrent episodes of post-exercise renal stress [27].

7. Conclusions

Hematuria, proteinuria, and albuminuria may occur transiently after intense physical exercise. However, their interpretation requires consideration of the timing of onset, exercise conditions, hydration status, and concomitant clinical symptoms. A single abnormal result obtained immediately after exercise should therefore not be interpreted in isolation from this context.

In the case of hematuria, it is crucial to confirm the presence of red blood cells via microscopic examination and, if necessary, to assess their morphology. Albuminuria and proteinuria should be quantified using ACR and PCR, respectively. Creatinine should be interpreted with caution after intense exercise, whereas novel biomarkers such as uKIM-1 and uNGAL currently remain primarily research tools.

Persistent or recurrent abnormalities, features suggestive of a glomerular origin of hematuria, impaired renal function, or symptoms suggestive of rhabdomyolysis should prompt further diagnostic evaluation. More standardized studies with long-term follow-up are needed to better define the clinical significance of recurrent post-exercise renal changes.

Author's contribution:

Conceptualization: Alicja Czajka

Methodology: Anna Banaś, Jan Caruk, Magdalena Młynarczyk

Software: Not applicable

Check: Paweł Szkup

Formal analysis: Iga Śliczniak, Dawid Czarnacki

Investigation: Kvitoslava Lukovych, Jan Ciesielczyk

Sources: Alicja Czajka

Data curation: Jan Caruk, Angelika Cięszczyk

Draft preparation: Alicja Czajka, Anna Banaś, Iga Śliczniak, Angelika Cięszczyk

Writing review and editing: Paweł Szkup, Kvitoslava Lukovych

Visualization: Jan Ciesielczyk, Dawid Czarnacki

Supervision: Alicja Czajka

Project administration: Alicja Czajka, Magdalena Młynarczyk

Receiving Funding:

Not applicable.

All authors have read and agreed to the published version of the manuscript.

Funding Statement:

This research received no external funding.

Institutional Review Board Statement:

Not applicable.

Informed Consent Statement:

Not applicable.

Data Availability Statement:

Not applicable.

Acknowledgments:

Not applicable.

Conflict of Interest Statement:

The authors declare no conflict of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process.

During the preparation of this work, the authors used ChatGPT to improve the clarity and readability of the text and to assist with basic data analysis. The authors reviewed and edited the generated content where necessary and take full responsibility for the final content of the publication.

References

1. Lippi G, Sanchis-Gomar F. Exertional hematuria: definition, epidemiology, diagnostic and clinical considerations. Clin Chem Lab Med. 2019;57(12):1818-1828. https://doi.org/10.1515/cclm-2019-0449.

2. American Urological Association (AUA); Society of Urodynamics, Female Pelvic Medicine & Urogenital Reconstruction (SUFU). Microhematuria: AUA/SUFU Guideline (2020, Amended 2025) [Internet]. 2025. Available from: https://www.auanet.org/guidelines-and-quality/guidelines [cited 2026 Sep 8].

3. Kidney Disease: Improving Global Outcomes (KDIGO) CKD Work Group. KDIGO 2024 Clinical Practice Guideline for the Evaluation and Management of Chronic Kidney Disease. Kidney Int. 2024;105(4S):S117-S314. https://doi.org/10.1016/j.kint.2023.10.018.

4. Aponte Becerra L, Mansour SG. Exercise and Kidney Health: Core Curriculum 2026. Am J Kidney Dis. 2026;87(2):246-259. https://doi.org/10.1053/j.ajkd.2025.09.014.

5. Tidmas V, Brazier J, Bottoms L, Muniz D, Desai T, Hawkins J, Sridharan S, Farrington K. Ultra-Endurance Participation and Acute Kidney Injury: A Narrative Review. Int J Environ Res Public Health. 2022;19(24):16887. https://doi.org/10.3390/ijerph192416887.

6. Wołyniec W, Ratkowski W, Kasprowicz K, Małgorzewicz S, Aleksandrowicz E, Zdrojewski T, Wierucki Ł, Puch-Walczak A, Żmijewski P, Renke M. Factors influencing post-exercise proteinuria after marathon and ultramarathon races. Biol Sport. 2020;37(1):33-40. https://doi.org/10.5114/biolsport.2020.89939.

7. Juett LA, Midwood KL, Funnell MP, James LJ, Mears SA. Hypohydration produced by high-intensity intermittent running increases biomarkers of renal injury in males. Eur J Appl Physiol. 2021;121(12):3485-3497. https://doi.org/10.1007/s00421-021-04804-3.

8. Urakami S, Ogawa K, Oka S, Hayashida M, Hagiwara K, Nagamoto S, Sakaguchi K, Yano A, Kurosawa K, Okaneya T. Macroscopic hematuria caused by running-induced traumatic bladder mucosal contusions. IJU Case Rep. 2019;2(1):27-29. https://doi.org/10.1002/iju5.12030.

9. Chen KH, Lee CH, Chen PY, Li LH, How CK, Lin YK, Chiu YH, Wang FL, Kao WF, Huang MK, Chien DK, Chang WH. Athletic pseudonephritis in male cross-country ultra-marathoners: a comparative observational study. Front Physiol. 2025;16:1608584. https://doi.org/10.3389/fphys.2025.1608584.

10. Vauthier JC, Touze C, Mauvieux B, Hingrand C, Delaunay PL, Besnard S, Jouffroy R, Noirez P, Maboudou P, Parent C, Heyman E, Poussel M. Increased risk of acute kidney injury in the first part of an ultra-trail-Implications for abandonment. Physiol Rep. 2024;12(9):e15935. https://doi.org/10.14814/phy2.15935.

11. Juett LA, Drury JE, Greensmith TB, Thompson AP, Funnell MP, James LJ, Mears SA. Hypohydration induced by prolonged cycling in the heat increases biomarkers of renal injury in males. Eur J Appl Physiol. 2024;124(4):1085-1096. https://doi.org/10.1007/s00421-023-05328-8.

12. Atkins WC, Butts CL, Kelly MR, Troyanos C, Laursen RM, Duckett A, Emerson DM, Rosa-Caldwell ME, McDermott BP. Acute Kidney Injury Biomarkers and Hydration Outcomes at the Boston Marathon. Front Physiol. 2022;12:813554. https://doi.org/10.3389/fphys.2021.813554.

13. Linder BA, Jeong S, Stute NL, El-Kurd OB, Vondrasek JD, Pasternak A, Bagley JR, Watso JC, Schlader ZJ, Babcock MC, Grosicki GJ, Robinson AT. Hypohydration augments the acute increase in urinary biomarkers of kidney injury following the 100-mile Western States Endurance Run. J Appl Physiol (1985). 2025;139(5):1379-1391. https://doi.org/10.1152/japplphysiol.00289.2025.

14. Newmire DE, Filep EM, Wainwright JB, Webb HE, Willoughby DS. Hydration Status and Acute Kidney Injury Biomarkers in NCAA Female Soccer Athletes During Preseason Conditioning. Nutrients. 2025;17(13):2185. https://doi.org/10.3390/nu17132185.

15. Pannone E, Abbott R. What is known about the health effects of non-steroidal anti-inflammatory drug (NSAID) use in marathon and ultraendurance running: a scoping review. BMJ Open Sport Exerc Med. 2024;10(1):e001846. https://doi.org/10.1136/bmjsem-2023-001846.

16. Specht JW, Bailly AR, Garcia S, Klepacz S, Andrade DE Oliveira S, Lucero D, McKenna ZJ, Schlader ZJ, Amorim FT. Effect of Ibuprofen on Markers of Acute Kidney Injury, Intestinal

Injury, and Endotoxemia after Running in the Heat. Med Sci Sports Exerc. 2025;57(6):1092-1102. https://doi.org/10.1249/MSS.0000000000003659.

17. Saha MK, Massicotte-Azarniouch D, Reynolds ML, Mottl AK, Falk RJ, Jennette JC, Derebail VK. Glomerular Hematuria and the Utility of Urine Microscopy: A Review. Am J Kidney Dis. 2022;80(3):383-392. https://doi.org/10.1053/j.ajkd.2022.02.022.

18. Lee AJ, Bang HI, Lee SM, Won D, Kang MS, Choi HJ, Lee IH, Jeon CH. Comparison of Urinary Red Blood Cell Distribution (URD) and Dysmorphic Red Blood Cells for Detecting Glomerular Hematuria: A Multicenter Study. J Clin Lab Anal. 2025;39(5):e25159. https://doi.org/10.1002/jcla.25159.

19. Stacey MJ, Hill NE, Parsons IT, Wallace J, Taylor N, Grimaldi R, Shah N, Marshall A, House C, O'Hara JP, Brett SJ, Woods DR. Relative changes in brain and kidney biomarkers with Exertional Heat Illness during a cool weather marathon. PLoS One. 2022;17(2):e0263873. https://doi.org/10.1371/journal.pone.0263873.

20. Leucuța DC, Trif LI, Almășan O, Popa SL, Ismaiel A. Acute Kidney Injury Biomarkers in Marathon Runners: Systematic Review and Meta-Analysis. Medicina (Kaunas). 2025;61(10):1775. https://doi.org/10.3390/medicina61101775.

21. Loureiro ACC, Nocrato GF, Correia ALL, de Matos RS, Nunes Filho JCC, Daher EF, Pinto FHM, de Oliveira AC, Ceccatto VM, Fortunato RS, de Carvalho DP. Serum and Urinary Neutrophil Gelatinase-Associated Lipocalin Are Not Associated With Serum Redox Parameters in Amateur Athletes After an Ultramarathon. Front Physiol. 2022;13:811514. https://doi.org/10.3389/fphys.2022.811514.

22. Kawakami S, Yasuno T, Kawakami S, Ito A, Fujimi K, Matsuda T, Nakashima S, Masutani K, Uehara Y, Higaki Y, Michishita R. Effects of high-intensity intermittent exercise versus moderate-intensity continuous exercise on renal hemodynamics assessed by ultrasound echo. Physiol Rep. 2024;12(2):e15925. https://doi.org/10.14814/phy2.15925.

23. Murawska-Ciałowicz E, Gomes de Assis G, Ciałowicz M, Bakońska-Pacoń E. Risk of Rhabdomyolysis and Kidney Injury after Intensive Exercise. Potential of Novel Biomarkers of Kidney Injury: A Narrative Review. J Hum Kinet. 2026;101(Spec Issue):199-226. https://doi.org/10.5114/jhk/218100.

24. Chapman CL, Holt SM, O'Connell CT, Brazelton SC, Howells WAB, Medved HN, Reed EL, Wiedenfeld Needham K, Halliwill JR, Minson CT. Acute kidney injury biomarkers and hydration assessments following prolonged mild hypohydration in healthy young adults. Am J Physiol Renal Physiol. 2023;325(2):F199-F213. https://doi.org/10.1152/ajprenal.00086.2023.

25. Kruijt N, Laforet P, Vissing J, Bhai S, Stemmerik MG, Kleefeld F, Voermans NC; 276th ENMC workshop participants. 276th ENMC International Workshop: recommendations on optimal diagnostic pathway and management strategy for patients with acute rhabdomyolysis worldwide. 15th-17th March 2024, Hoofddorp, The Netherlands. Neuromuscul Disord. 2025;50:105344. https://doi.org/10.1016/j.nmd.2025.105344.

26. Vangstad M, Birkeland JAK, Gulsvik AK, Ervik RL, Oftebro I, Brekke FB, Akkouh OA, Jacobsen D, Bjornaas MA. Exertional rhabdomyolysis: clinical features, management, complications and prediction of acute kidney injury. BMJ Open Sport Exerc Med. 2026;12(1):e003214. https://doi.org/10.1136/bmjsem-2026-003214.

27. McKenna ZJ, Atkins WC, Babcock MC, Grosicki GJ, Linder BA, McDermott BP, Robinson AT. Kidney injury risk during prolonged endurance running: lessons from the field. J Appl Physiol (1985). 2026;140(3):630-637. https://doi.org/10.1152/japplphysiol.01228.2025.