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REVIEWS

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ACUTE EFFECTS OF EXERCISE ON BLOOD IRISIN LEVEL: A SYSTEMATIC REVIEW

AKUTNI UČINCI TJELOVJEŽBE NA RAZINU IRIZINA U KRVI: SUSTAVNI PREGLEDNI RAD

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ABSTRACT

Irisin is a myokine with important autocrine, paracrine, and endocrine functions in the body. The acute effect of exercise on circulating irisin levels is not entirely explored. The aim of this review was to analyze the acute effects of exercise on blood irisin level, with respect to the type and intensity of exercise, environmental conditions in which the exercise is performed, and participants' age, sex, fitness level and health status. Web of Science and Scopus were searched. Sixty-two articles met the inclusion criteria and were included in the analysis. Both endurance and resistance training seem to have a positive acute effect on blood irisin level, with higher-intensity possibly having a superior potential to induce these changes. The evidence on the effect of environmental conditions is still inconclusive. Age, sex and fitness level do not seem to affect irisin responsiveness to exercise. The results on persons with health (mainly metabolic) disturbances indicate a positive effect, but are still inconclusive.

Key words: myokines, endurance training, resistance training, intensity of exercise

SAŽETAK

Irizin je miokin s važnim autokrinim, parakrinim i endokrinim zadaćama u tijelu. Akutni učinak tjelovježbe na razinu cirkulirajućeg irizina nije u potpunosti istražen. Cilj ovoga pregleda bio je analizirati akutne učinke tjelovježbe na razinu irizina u krvi, s obzirom na vrstu i intenzitet tjelovježbe, uvjete okoliša u kojima se tjelovježba provodi te dob, spol, razinu tjelesnih sposobnosti i zdravstveni status vježbača. Učinjena je pretraga baza Web of Science i Scopus. Uključne kriterije zadovoljila su 62 članka koja su uvrštena u završnu analizu. Analiza ukazuje na pozitivan akutni učinak treninga izdržljivosti i treninga s opterećenjem na razinu irizina u krvi, s mogućim značajnijim potencijalom tjelovježbe višega intenziteta za izazivanje takvih promjena. Dokazi o utjecaju okolišnih temperaturnih uvjeta za sada su nedovoljni za donošenje konkretnijih zaključaka. Također, izgleda da dob, spol i razina fitnesa ne utječu na reakciju irizina na tjelovježbu. Rezultati dobiveni na ispitanicima sa zdravstvenim poteškoćama (uglavnom metaboličkim) ukazuju na pozitivan učinak, ali su također nedovoljni za donošenje sigurnijih zaključaka.

Ključne riječi: miokini, trening izdržljivosti, trening s opterećenjem, intenzitet tjelovježbe

INTRODUCTION

Myokines are cytokines released by muscle cells during muscle contractions into the bloodstream, serving autocrine, paracrine and endocrine functions[18,89], allowing communication between muscles and other organs.[77] In 2012 Boström et al.[13] first showed that expression of the transcriptional coactivator PGC-1α (peroxisome-proliferator-activated receptor-γ (PPAR-γ) coactivator 1α) in muscles stimulates the expression of the fibronectin type III domain-containing protein 5 (FNDC5) and the release of the myokine irisin into the bloodstream of mice. Irisin has many autocrine, paracrine, and endocrine functions in the body and has since its discovery raised considerable interest.[6,57,59]

The early studies on irisin already pointed to its different functions, such as irisin's role in the metabolic health via its influence on the fat tissue. Fat is stored in the human body as white (WAT) and brown adipose tissue (BAT), with mutually antagonistic functions – WAT serving as a depot of energy (triglycerides) and BAT generating heat given its high density of mitochondria.[87] Boström et al.[13] have shown that *in vivo* and *in vitro* irisin administration enhances thermogenesis and energy consumption in mice, partly through conversion of WAT into BAT. In this manner, irisin could influence body mass regulation and body fat percentage, important predictors of all-cause mortality. Interestingly, humans and mice share 100% of irisin DNA, while that similarity is 85% and 90% for insulin and glucagon, respectively.[13]

Furthermore, a study by Huh et al.[39] has shown that myocytes exposed to irisin increase their uptake of glucose and fatty acids, while also showing that irisin causes increased expression of genes that code for glucose transporter GLUT-4. In a similar study, Lee et al.[55] have shown that rat myocytes, exposed to irisin, increase their uptake of glucose, through translocation of glucose transporter GLUT-4 on cell membrane. In their meta-analysis, Jia et al.[44] have determined that people with obesity have significantly elevated blood irisin levels in comparison to control normo-weight people. That effect was larger for children compared to adults.[44]

In accordance with the aforementioned results, the meta-analysis of Qiu et al.[81] has shown that there is a weak, albeit significant negative relationship between circulating irisin levels and insulin sensitivity. Perakakis et al.[78] state that "hyperirisinemia" (i.e., response to irisin resistance) could be a defense mechanism, by which the organism strives to maintain the glucose homeostasis in type 2 diabetes and obesity.

Numerous studies and reviews have documented positive effects of exercise, especially endurance exercise, on executive functions, hippocampus size and neuroplasticity.[21,28,38] These exercise effects are partly mediated through neurotrophins, especially brain-derived neurotrophic factor.[79] Wrann et al.[103] have shown that there is a link between irisin secretion and BDNF in the hippocampus after 30 days of exercise, concluding that expression of transcription coactivator PGC-1α and FNDC5 leads to BDNF expression in the hippocampus. The role of irisin as a potential mediator of positive effects of exercise on brain health via different pathways has since been confirmed in many studies.[86]

Several studies pointed to a therapeutic role of irisin in bone healing. Serbest et al.[88] have shown that irisin plays a role in bone healing, documenting significantly elevated irisin levels 60 days after a fracture, compared to the first and 15th day after the fracture. Colaianni et al.[20] have shown that irisin injection prevented bone mineral loss in mice with suspended hind legs.

Many studies have investigated different aspects of the influence of exercise on blood levels of irisin, and previous reviews analyzed the acute and chronic effects of exercise on blood level of irisin.[43,65,92] Jandova et al.[43] found a positive long-term effect of exercise on increase in blood irisin, although with considerable heterogeneity among the analyzed studies, primarily attributed to the methodological reasons (laboratory detection of irisin). Similar results were confirmed for the effect of exercise in persons with overweight or obesity in the review by Bernal Rivas et al.[8] The results of Mohammad Rahimi et al.[65] confirmed the positive long-term effects. Vecchiato et al.[100] suggested high-intensity training as preferred to increase irisin in patients with type 2 diabetes, and Torabi et al.[92] concluded the same for high-intensity interval training in overweight and obese adults. Kazeminasab et al. compared the effect of different types of acute and chronic exercise on circulating irisin.[51] Acute exercise had a stronger effect on blood irisin increase, with acute aerobic exercise having superior effect than acute anaerobic exercise, whereas the same was true for resistance training (RT) in terms of chronic effects.[51] Cosio et al. confirm the chronic effect of resistance training, especially in older persons, but, as do Jandova et al.[43], emphasize the importance of robust laboratory methods for irisin detection.[25] In terms of endurance training, acute positive effects have been confirmed.[26] Although previous reviews already analyzed some of the aspects of exercise effect on circulating irisin, different contexts of exercise, characteristics of participants and environmental conditions are still not enough explored. The aim of this article was to provide an overview of the acute effects of exercise on blood irisin level, with respect to the type of exercise and exercise intensity, participants' age, sex, fitness level and health status, and environmental conditions in which the exercise is performed.

METHODS

Search protocol and study selection

This review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines in design, analysis and result reporting.[74] To obtain relevant scientific articles that have examined the acute effect of exercise on blood irisin levels, two scientific databases were searched: Web of Science and Scopus. The search was performed on January 9th 2024. Key words searched were "irisin" and "acute exercise". To be included in the review, the articles had to be published in a peer-reviewed publication, in English language, some form of acute exercise had to be undertaken and either plasma or serum irisin levels measured before and after exercise. No limits were placed on the participant age, date of publication or study design. Each author independently checked article titles to exclude duplicate publications and abstracts to exclude the articles that did not fulfill the inclusion criteria. The authors searched the references of the articles included in the final analysis to identify possible additional articles of interest. Any disagreements were consensually resolved.

Study quality assessment

National Heart, Lung, and Blood Institute's Study Quality Assessment Tools were used to perform Quality Assessment of Controlled Interventional Studies, and Quality Assessment Tool for Before-After (Pre-Post) Studies With No Control Group.[67] Quality assessment tool for controlled interventional studies allows rating the study quality as good, fair, or poor, based on 14 items assessing procedure of randomization and blinding, baseline characteristics of participant groups, adherence and drop-out rate, other interventions, outcome measurement, calculation of sample size, and intention-to-treat analysis.[67] Quality Assessment Tool for Before-After (Pre-Post) Studies With No Control Group also allows for rating the study quality as good, fair, or poor, based on 12 items assessing study questions, participants selection and representativeness, adequacy of the sample size, quality of intervention and outcome measurement, loss to follow-up, and quality of the statistical analysis.[67] Each author assessed the studies independently. Disagreements were consensually resolved. The risk of bias was estimated, i.e., the quality rating was assigned to the studies based on the number of affirmative answers to the abovementioned criteria, following this classification: ≥ 75% affirmative answers = good (low risk of bias), 50–75% = fair, < 50% = poor (a higher risk of bias).[17] The rating of the study quality is presented in Table 1.

RESULTS

Literature search yielded a total of 264 articles, 143 in Web of Science and 121 in Scopus database. After the removal of the duplicates (n=102), 162 articles remained. After careful examination of the abstracts, 102 articles were excluded from further analysis as they did not fulfill the inclusion criteria (reviews, not experimental trials, articles that did not implement any kind of acute exercise, and articles that did not report measured blood irisin levels before and after exercise). Articles' reference lists were searched for additional studies. This search yielded 27 additional articles, out of which ten were excluded from further analysis. In total, 62 articles have met the inclusion criteria and were included in the final analysis. The literature search protocol, performed by both authors, is depicted in the flow diagram in Figure 1.

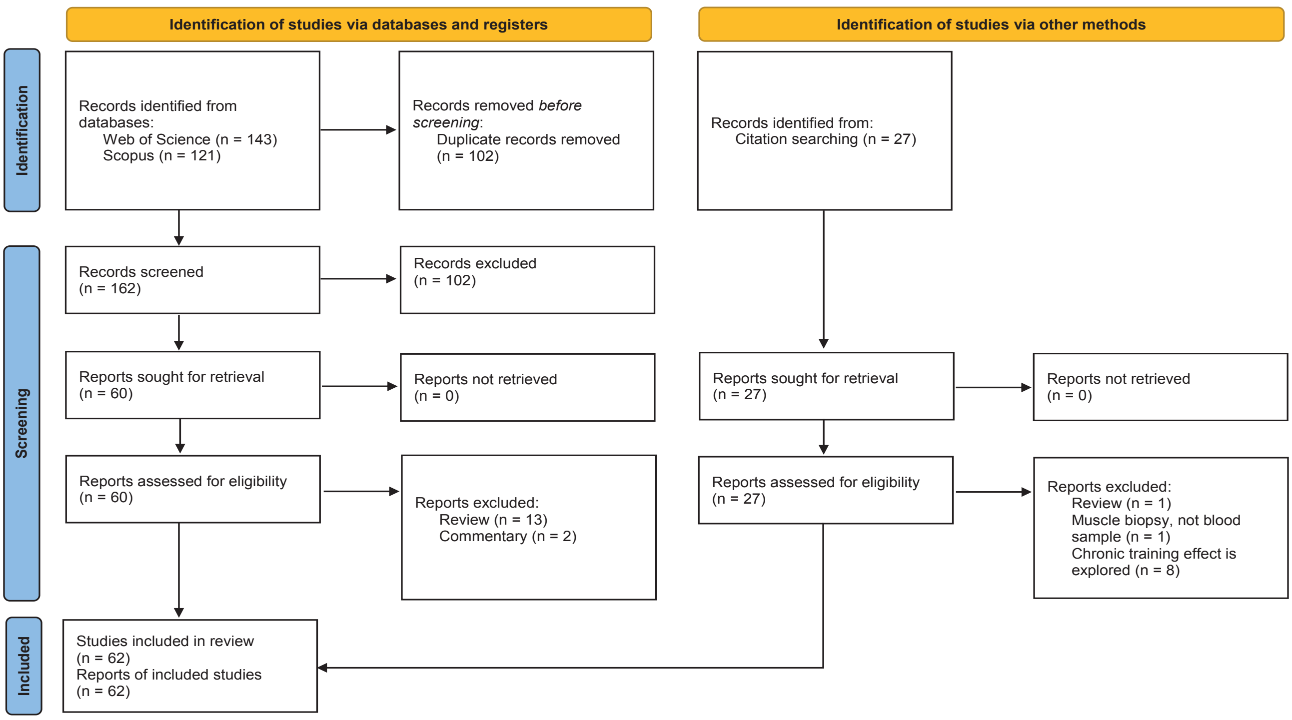

Figure 1. The flow diagram of the literature search protocol[74]
Slika 1. Dijagram protokola pretraživanja literature

Table 1. Characteristics of the studies that investigated the acute effect of exercise on blood irisin

Tablica 1. Karakteristike studija koje su istraživale akutni učinak vježbanja na irizin u krvi

First author, year, country	Study aim	Study design	Participants Total number (N), Groups, F/M, Age (years)[a]	Characteristics of acute exercise	Blood sample, sampling time (before/after exercise)	Results	Q
1. Qiu, 2018, Germany[82]	Effects of different exercise modes and training status on **serum** irisin	Randomized cross-over trial	**Study 1 (S1):** healthy adult men (N=16) **Trained** (N=8, 27.4±3.8) **Untrained** (N=8, 24.7±2.5) **Study 2 (S2):** healthy adults (N=17, **9F** (26.3), **8M** (27.4))	**S1)** 50-min cycling at 80% of VO_{2max} **S2) a)** cycle ergometer GXT (25W increase/3min; duration 25.0± 6.0 min) **b)** treadmill GXT (1.5% incline, 1.44km/h increase/3min; duration 18.5±5.4 min)	**S1)** Before, 10 min after and 180 min after **S2)** Before, immediately after, 10 min and 60min after	**S1) 10-min after:** ↑ both groups **180 min:** baseline levels. = **S2) Immediate:** ↑ after both **10-min after:** running still ↑; cycling baseline **60 min:** baseline for both	F
2. Arıkan, 2018, Turkey[5]	Effects of taekwondo training on **plasma** irisin	Pre-Post	Elite taekwondo athletes (N=13) 6F: 20.2±0.9 7M: 19.3±0.5	Taekwondo training session: 120 minutes, 70-80% intensity	Fasted, before and after	M/F: ↔ No effect of sex, no exercise-sex interaction	F
3. Kabak, 2018, Turkey[49]	Effects of HIIT on **plasma** irisin in kick-boxers and CG	NRCT	**EG:** recreationally trained male kickboxers (N=10, 20.2±1.6) **CG:** sedentary males (N=10, 20.0±1.3)	HIIT: 4x30 s cycle ergometer sprint, 4-min rest between sets.	Before, immediately after, and 3 and 6 h after	**Baseline:** EG vs CG + **Immediate:** ↓ in both groups (+↓ in EC)	F
4. Huh, 2014, Greece[40]	Effects of whole-body vibration exercise (WBV) on **serum** irisin	Pre-Post	Healthy untrained women (N=14, 24.3±2.6)	Six-week WBV training of moderate intensity: 7 isometric full-body exercises; progressive increase in: vibration frequency, amplitude, duration	Before and after the first and the last (at 6 weeks) session	**Baseline:** = between two trials **After:** ↑ in both trials (+ %change after 6 weeks)	F
5. Tsuchiya, 2015, Japan[95]	Effects of time-matched exercise modes on **plasma** irisin	Randomized cross-over trial	Physically active males (N=10, (mean±SE): 23±1)	Three 60-min sessions: RT: 8 exercises, 3-4 sets, 12 reps, 65% of 1RM ET: pedaling at 65% of VO_{2max} RET: 30 min RT + 30 min ET	Before, immediately after and at 0.5, 1, 2, 3, 4, and 6 h after	**1 hour after:** ↑ after RT; ↔ after ET and RET **6 hours after:** + RT vs RET	F
6. Blizzard LeBlanc, 2017, Canada[12]	Effects of RT and ET session on **plasma** irisin	Pre-Post	Obese adolescents (N=11, 5F/6M); 15.7±0.5)	ET: 45-min cycling, at 60% HRR RT: full body routine (5 exercises, 4 sets, 12-15 reps, 60-65% of 1RM, 60 s rest), 45 min in total	Before, during (15, 30 min) and after	ET: ↑ RT: ↔	F

7. Tsai, 2021, Taiwan[93]	Effects of HIIT and MICE on **serum** irisin	Balanced cross-over trial	Healthy late middle-aged and older adults (N=21, 11F/10M; 60.6±5.0)	1. HIIT: 24-min HIIT (1 min at 70-75% HRR, 2 min recovery at RPE 9-11) 2. MICE: 24-min MICE (50-55% HRR) 3. REST: 35-min sitting	Before and 5 min after	HIIT: ↑ MICE: ↔ REST: ↔	F
8. Norheim, 2014, Norway[69]	Effects of exercise on **plasma** irisin in normo- and overweight, pre-diabetic individuals	NRCT	Inactive adult men (N=26, age 40-65 y): 1. Prediabetic (N=13) 2. Normal weight controls (N=13)	45 minutes cycling at 70% VO_{2max}, at baseline and after a 12-week ET and RT program (two 60-min ETs and two 60-min RTs per week)	Before, immediately after and 2 hours after the first and last (at 12 weeks) training session	**Baseline:** + prediabetic group vs CG at both trials **Immediate:** CG ↑ at both trials Prediabetic ↑ at 2nd trial	F
9. Wiecek, 2018, Poland[101]	Effects of a single anaerobic exercise on **plasma** irisin	Pre-Post	Healthy, active Caucasian adults, non-smokers (N=20) 10F: 22.6±1.5 10M: 21.6±1.2	A single 20-s sprint on cycle ergometer; highest possible cadence for the entire bout	Before, and 3, 15, 30, 60 min and 24h after	**F: Immediate:** ↔ **15, 30, 60 min after:** ↑ 24 h: baseline level **M:** ↔	F
10. Löffler, 2015, Germany[58]	Effects of four exercise modalities on **serum** irisin in 1) children and 2) young adults	Pre-Post	**1) Children** (N=29, age 14): - lean (8F/11M) - obese (8F/2M) **2) Adults** (N=28): - lean (7F/7M, 24.1±3.0) - obese (7F/7M, 25.8±5.3)	**Children:** 15-min maximum spiroergometric test on cycle ergometer. **Adults:** 30-min program (10-min jogging, 10-min gymnastics, 10-min sprint).	Before and immediately after	**Children:** +↑, regardless of sex and BMI (↔ only for obese M) **Adults:** ↑ in 70% of the participants (lean M/obese F).	F
11. Tsuchiya, 2014, Japan[94]	Effects of two energy expenditure-matched running trials on **serum** irisin	Within-subject randomized cross-over trial	Healthy sedentary males (N=6, (mean±SE): 22.5±1.1)	Low-intensity exercise (LIE): 40-min treadmill running at 40% of VO_{2max} High-intensity exercise (HIE): 20-min treadmill running at 80% of VO_{2max}	Before, immediately after, and 3, 6 and 19 h after	+ LIE vs HIE **3 and 6 h after:** + LIE vs HIE **HIE:** ↔ **LIE:** ↓ immediate	F
12. Archundia-Herrera, 2017, Mexico[4]	Effects of MICE and HIIT on **plasma** irisin in overweight/ obese female adolescents	Pre-post, two groups	Sedentary overweight/ obese adolescent females (N=30). 1. **MICE** (N=15, 15.5±1.7) 2. **HIIT** (N=15, 16.1±1.6)	MICE: 40 min ergometer cycling at 65% HRpeak HIIT: 6x1 min at 85–95% HRpeak, separated by 1-min low-intensity recovery	Fasted, before and 30 min after	MICE: ↔ HIIT: ↔	G
13. Algul, 2017, Turkey[2]	Effects of aerobic exercise on **serum** irisin in relation to time and training status	Randomized cross-over study	Young men (N=60): **1) trained** (N=30, 19.2±0.7) **2) untrained** (N=30, 19.5±0.6)	30-min outside running at 64–76% HRmax, two occasions (morning, evening), 72 h apart	Before and immediately after	**Baseline:** + trained vs untrained at both times **After:** ↑ in both groups, irrespective of the time of day	F

14. Zügel, 2016, Germa-ny[104]	Effects of sex and body fat % on **serum** irisin after incremental exercise	Pre-post, two groups	1) **Lean adults** (N=16; **9F** (26.3±5.4), **7M** (25.8±6.8)) 2) **Morbidly obese adults** (N=12; **7F** (52.8±14), **5M** (54.2±8.1))	**Lean participants:** GXT cycle ergometer **Obese participants:** modified treadmill walking test till exhaustion (~10 min).	Before and immediately after + 10 and 60 min after (only in lean participants).	**Baseline:** = between sexes; + obese vs lean **After:** ↑ in lean M and F ↔ in obese (M/F)	F
15. Comassi, 2015, Italy[23]	Effects of ultra-endurance events on **plasma** irisin	Pre-Post, two groups	Highly-trained male ultra-endurance athletes (N=27): 1. **Ironman** (IR, N=14, 40.9±7.2) 2. **Half Ironman** (HIR, N=13, 42.9±8.0)	**IR** race: mean duration 12:48:21±1:14:18 h **HIR** race: mean duration 6:14:43±0:37:25 h	Before and after	**HIR:** slight ↑ **IR:** ↔	P
16. Huh, 2014, USA/ Greece[39]	1) Effects of exercise on **plasma** irisin with respect to age and fitness level, 2) Effect of exercise intensity on plasma irisin levels	NRCT	**Study 1 (S1):** Healthy men (N=78), grouped based on: a) **age** (38 young (26.7±4.1) and 40 old (67.9±5.0)) b) **fitness level** (38 active (48.7±21.4) and 40 sedentary (47.0±21.3) **Study 2 (S2):** Healthy adolescent swimmers (**15F** (15.4±0.3), **15M** (15.4±0.2)	S1) 45-min treadmill running at 70–75% VO_{2max}, followed by running to exhaustion at 90% VO_{2max}. S2) MICE: 2000 m freestyle swimming (velocity 1.2±0.0 m/s) HIIT: 6x 50-m maximal freestyle swimming, every 5 min (velocity 1.6±0.0 m/s).	S1) Before and immediately after (10-15 min) S2) Before, immediately after, 1 h and 24 h after	**S1) Baseline:** + young vs old; + sedentary vs active **Active:** ↑ all participants, no effect of age or fitness level **S2) MICE:** ↔ **HIIT:** ↑ (+ M), return to baseline after 1 h	F
17. Briken, 2016, Germany[14]	Effects of endurance exercise on **serum** irisin in people with multiple sclerosis (MS)	RCT	Persons with progressive MS (N=42, 25F/17M, 50.0±7.5)	GXT on a cycle ergometer (12.5 W/ min or 8 W/min increase).	Before, after and 30 minutes after	After: ↔	F
18. Reycraft, 2020, Canada[83]	Effects of acute exercise of different intensities (4 protocols) on **plasma** irisin	Cross-over trial, counter-balanced	Active young men (N=8, 23.1±3.0)	1. REST: control, no exercise 2. MICE: 30-min running at 65% of VO_{2max} 3. VICE: 30-min running at 85% of VO_{2max} 4. SIT: 4x30 s 'all out' running, 4min passive rest in-between.	30 min before exercise, immediately after, and 30 min and 90 min after	**REST, MICE, SIT:** ↔ **VICE:** ↑ (+ 30-min post-exercise vs immediately after)	F
19. Bilski, 2020, Poland[9]	Effects of one maximal sprint-cycling bout on **plasma** irisin	Cross-over trial	Moderately active male firemen (N=26, 28.7±4.1)	Two Wingate tests on cycle ergometer (30s maximal sprint, constant resistance of 7.5% of body mass) on two separate days	30 min before, immediately after	↑ on both days	F

20. Ozbay, 2020, Turkey[71]	Effects of exercise in different temperature conditions on **serum** irisin	Pre-Post, two groups	Healthy males (N=32; indoor group (IG, N=16, 22.6±1.6) and outdoor group (OG, N=16, 21.3±2.4)	40-minute running at 50%–55% VO_{2max}. Environmental temperature: IG: 21°C–25°C; OG: −5°C–5°C	Before and after	Small ↑ in both groups, =	F
21. Daskalopoulou, 2014, Canada[27]	Effects of different-intensity exercises on **plasma** irisin	Randomized cross-over trial	**Healthy adults:** Pilot study (N=4, 2F/2M, 22.5±1.7) **Main study** (N=35, 15F/20M, 23.0±3.3)	**Pilot study:** GXT (modified Bruce protocol). **Main study: 1)** maximal workload – as in pilot study; **2)** relative workload: 10-min treadmill running at 70% of VO_{2max}; **3)** absolute workload: 10-min cycling at 75 W.	Before and 3-min after	**Pilot study:** ↑ **Main study:** all three protocols ↑ VO_{2max} correlation with ↑	F
22. Szumilewicz, 2019, Poland[90]	Effects of exercise on **serum** irisin in pregnant women	NRCT	Pregnant nulliparous women (N=20, 30±3 y). **1) TG** (completed a 6-week training program, N=8): **2) CG** (N=12)	60-min moderate- to high-intensity exercise session (warm up, 25-min high-low impact aerobics, 25-min resistance exercises, 10-min pelvic floor exercises, stretching and breathing and relaxation)	Before and 30 min after	**Baseline:** = **TG:** ↑ **CG:** diversified results (↑ 7F, ↓ 5F)	F
23. Ozcelik, 2018, Turkey[72]	Effects of football game at different times of day on **plasma** irisin	Pre-Post	Trained young males (N=20, 18.4±0.1)	Three 60-min soccer matches played at different time points (in the morning, afternoon and evening), 3 days apart each	Before and after	**Baseline:** + afternoon/ evening vs morning **After:** ↑ in all three occasions	F
24. Jurimae, 2021, Estonia[48]	Effects of prolonged rowing on **plasma** irisin	Pre-Post	Highly trained female rowers (N=15, 18.3±1.6)	One-hour rowing ergometer exercise (12.1±1.1 km), intensity 70% VO_{2max}	Before, after and 30 minutes after	**After:** small ↑ related to VO_{2max} and weekly training volume	F
25. Jurimae, 2021, Estonia[47]	Effects of prolonged rowing on **serum** irisin	Pre-Post	Highly trained male rowers (N=16, 19.0±2.2)	Two hours of long-distance rowing (sculling) (23.8±0.9 km), intensity 79.8±2.1% of the anaerobic threshold	Before, after and 30 minutes after	After: ↔	F
26. He, 2019, China[37]	Effects of two aerobic protocols on **serum** irisin	Cross-over trial, counter-balanced	Healthy, untrained males (N=14, 23±1)	1. FATmax: 45 min, treadmill, at FATmax intensity (~52% of VO_{2max}) 2. AT: 45 min, treadmill, at anaerobic threshold intensity (~85% of VO_{2max})	Before, immediately after and 1, 3, 24, 48 and 72 h after	↔ at any time point	F

27. He, 2018, China[36]	Effects of three protocols on **serum** irisin	Cross-over trial, counter-balanced	Healthy, non-athletic males (N=17, 23±2)	1. HIIT1 (short): 2x6x30 s treadmill running at vVO_{2max}, 90 s recovery at 50% vVO_{2max}, 4 min passive recovery between sets 2. HIIT2 (long): 5x4min at 90% of vVO_{2max}, 4 min recovery at 50% vVO_{2max}, between bouts. 3. RT: full body program, 7 exercises, 4 sets, 8-10 reps, 70-75% of 1RM.	Before, immediately after and 1, 3, 24, 48 and 72 h after	↔, no time nor condition by time effect	F
28. Bizjak, 2021, Germany[11]	Effect of fitness status on **serum** irisin in older adults	Pre-Post	Older adults (N=28, 16F/12M, 73.4±5.5) Two groups: HF/LF	Maximal graded exercise test (GXT) on cycle ergometer.	Before and after	**Baseline:** + HF vs LF **After:** ↔ irrespective of fitness level	F
29. Pradas, 2021, Spain[80]	Effect of a simulated padel competition on **plasma** irisin	Pre-Post	Trained padel players (N=24, 14F/10M, 27.8±6.3)	Simulated padel competition, average real playing time 27.8±8.49 min, intensity 75.2±7.9% HRmax	Before and after	↔, no between-sex pre/post differences	F
30. Marcucci-Barbosa, 2020, Brazil[60]	Effects of 10km road race on **plasma** irisin	Pre-Post	Recreational male runners (N=9, 32.2±10.2)	10km race, self-selected pace. Average finish time was 49.8±7.0 min	Before, after, and 24h after	**After:** ↔ **24h after:** ↑	F
31. Dündar, 2019, Turkey[30]	Effects of a handball training on **serum** irisin	Pre-Post	Adolescent male handball players (N=19, 16.1±0.8)	Warm up (30 min), stretching (10 min), conditioning, technical and tactical training (50 min), simulated handball match (30 min).	Before and after	↑	P
32. Moienneia, 2016, Iran[66]	Effects of RT on **serum** irisin	RCT	Sedentary healthy women (N=21, 24.4±3.0)	Circular RT training (4 lower- and 3 upper body exercises). LI (N=11): 40%-60% 1RM, 20-30 reps, work/rest ratio 45/30 s, 3 rounds) HI (N=10): 70%-90% 1RM, 5-15 reps, work/rest ratio 20/30 s, 3 rounds)	Before and after	**Baseline:** = **After:** ↔ within groups	F

33. Kara, 2022, Turkey[50]	Effects of different types of muscle contraction on **plasma** irisin	Repeated cross-sectional study	Healthy male athletes (N=16, 26.2±3.2)	Concentric (CON) and isometric (ISO) exercise on isokinetic dynamometer, 3 weeks apart: CON: 4 sets of 20 knee extension/flexion reps at 60°/s, maximal effort ISO: 4 sets of 6 maximum 5s knee-extensor contractions and 5s knee flexor contractions at 45°of knee flexion (0°full extension)	Before and immediately after	**CON:** ↑ **ISO:** ↔	F
34. Invernizzi, 2023, Italy[42]	Effect of a judo training on **plasma** irisin	Within-subject randomized cross-over trial	Male black belt judokas (N=11, 39.0±13.9)	Randori session: contact fighting 5 min per bout (33 min total), 2 min rest between bouts. Resting session: 33 min rest	30 min before, immediately after	↔	F
35. Mendez-Gutierrez, 2023, Spain[63]	Effects of ET and RT on **plasma** irisin	Cross-over study	Young sedentary adults (N=10, 6F/4M, 21.5± 2.3)	ET: maximal treadmill test, constant speed 5.3 km/h, incline increase 1% per min RT: maximum isometric strength test (leg press ad handgrip); 1RM test (bench and leg press).	Immediately before and 3, 30, 60 and 120 min after	**ET:** ↔ **RT:** ↔	F
36. Cokar, 2022, Turkey[19]	Effects of aerobic exercise on **serum** irisin in persons with type 2 diabetes mellitus	Pre-Post	Adult inactive females with type 2 diabetes mellitus (N=16, 57.5±7.4)	Treadmill exercise: 10-min warm-up, 40 min at 50–70% Karvonen target HR, 10-min cool-down	Before and immediately after	↔	F
37. Colpitts, 2022, Canada[22]	Effects of MICE and HIIT on **plasma** irisin in normal-weight and overweight/ obese youth	Randomized cross-over trial	Adolescents (N=25, 12F/13M): Normal weight (**NW**; N=14, 17.1±1.7) Overweight/obese (**OW**; N=11, 16.3±2.1)	MICE: 35 min cycling session at 50% of HRR HIIT: 35 min cycling session, 5x 5-min intervals at 50% HRR, followed by 2-min at 85%–90% HRR	Before, throughout (0, 7, 14, 21, 28 min) and immediately after	**Baseline:** = **HIIT, NW:** ↑, negative correlation of fat mass and LDL with irisin ↔ in both NW and OW, for both MICE and HIIT	F
38. Zuo, 2023, China[105]	Effects of different-intensity RT on **serum** irisin in young males	RCT	Young inactive males (N=18) **FRT** (functional RT, N=9, 24.2±1.8) **TRT** (traditional RT, N=9, 23.2±2.0)	FRT: 4–5 sets of 20 RM at 40% 1RM, whole-body workout, unstable surface TRT: 4–5 sets of 12 RM at 70% 1RM, whole-body workout	Before and immediately after	↑ in both groups	F

39. Missaglia, 2023, Italy[64]	Effects of cycle ergometer GXT on **serum** irisin	Pre-Post	Healthy adult men (N=5, 20-55)	Incremental cycle ergometer exercise till exhaustion.	Before, and 15 min, 24h, and 48h after	**15 min and 24h after:** ↑ **48 h after:** baseline level	P
40. Ghalamsiah, 2023, Iran[33]	Effect of high-intensity functional training (HIFT) with and without whole-body electro-myostimulation on **serum** irisin	Cross-over study	Overweight adults (N=13, 6F/7M, 41.1±8.2)	HIFT (25 min): 8-min warm-up, 17-min whole-body workout (10 exercises [30 sec with maximum effort, 20-sec active rest between exercises], 2 circuits, 1-min rest). HIFT + electromyostimulation (85 Hz, 400 µs, 10 s, 2-s breaks).	Immediately before and after	**HIFT:** ↑; + for HIFT+electro-myostimulation.	F
41. Kim, 2023, Australia[52]	Effects of HIIT on **serum** irisin in persons with advanced prostate cancer	Pre-Post	Persons with advanced prostate cancer (N=9, 67.8±10.1)	HIIT: 34 min on cycle ergometer (6 sets of 4-min intervals at 70-85% HRmax, 2-min active recoveries at 50-65% HRmax)	Before, immediately after and 30 min after	↔	F
42. Ercan, 2023, Turkey[31]	Effects of acute aerobic exercise on **serum** irisin in persons with rheumatoid arthritis (RA)	NRCT	Adults (N=80, 56F/24M): **RA** (rheumatoid arthritis patients, N=40, 45.3±9.6) **CG** (N=40, 44.1±6.3)	30-min treadmill walking at 60-80% HRmax	Before and immediately after	**Baseline and after:** + RA vs CG **RA, CG:** ↓	G
43. Cordingley, 2023, Canada[24]	Effect of BFR-RT on **plasma** irisin in young and older men, depending on their training status	Non-rando-mized uncontrolled study	Untrained adult males (N=15) **Younger** (N=8, 24.8±3.9) **Older** (N=7, 68.3±5.0)	1) Acute baseline BFR-RT: whole-body workout, 4 sets, 15 reps, 30% 1RM, 30-s between-set/2-min between-exercise rest 2) Acute BFR-RT after a 12-week whole-body training protocol (3 days per week, from 2 sets, 10 reps, 60% 1RM to 3 sets, 10 reps, 85% 1RM))	Before, immediately after, and 3, 6, 24 and 48 h after	+ after baseline vs trained condition ↑ only in older, in trained state, 6h after	F
44. McCormick, 2022, Canada[62]	Effects of prolonged exercise in two environmental thermal conditions on **serum** irisin in younger and older men	Exploratory study, two groups	Adult active men (N=24). **Young** (N=12, 22±3) **Older** (N=12, 59±4)	3-hour moderate-intensity treadmill walking (fixed metabolic rate ~200 W/m^2): 1) heat-stress: wet-bulb globe temperature (WBGT) 32°C 2) no heat-stress: WBGT 16°C.	Before, immediately after and 60 min after	+ young vs older at all time points **No-heat stress:** ↔ both groups **Heat stress:** ↑ both groups	F

45. Birinci, 2023, Turkey[10]	Effects of aerobic running and table tennis of **serum** irisin in master athletes	Quasi-experimental pretest–posttest design	Veteran male athletes (N=40) **Table tennis** (N=10, 56.0±4.4) **Running** (N=10, 56.7±5.7) **Chess** (N=10, 57.3±5.7) **CG** (N=10, 57.5±8.4)	**Table tennis:** 10-min warm-up, 40-min table tennis game at 70–75% of HRR **Running:** 10-min warm-up, 40-min indoor running at 70–75% of HRR **Chess:** 40 min chess game **CG:** resting	Before and immediately after	Table tennis: ↑	F
46. McCormick, 2022, Canada[61]	Effects of prolonged exercise in two thermal conditions on **serum** irisin in older men	NRCT (controlled, 3 groups, cross-over)	Active older men (N=31) **Healthy** (N=12, 59 ± 4) **Hypertensive** (N=10, 60 ± 4) **With type 2 diabetes** (N=9, 60±5)	3-hour moderate-intensity treadmill walking (fixed metabolic rate ~200 W/m^2): 1. heat-stress: wet-bulb globe temperature (WBGT) 32°C 2. no heat-stress: WBGT 16°C.	Before, immediately after, and 60 min after	↔ in temperate conditions, all groups ↑ in heat stress, all groups	F
47. Kraemer, 2016, USA[54]	Effect of BFR-RT on **plasma** irisin	Counter-balanced cross-over trial	Male students (N=8, 21.8±1.4)	**BFR-RT:** partial vascular occlusion, 3 sets single arm biceps curls and calf presses at 30% 1RM. **Moderate RT:** no occlusion, same exercises at 70% 1RM **Only occlusion:** no exercise	Before, immediately after and 15 min after	↑ in BFR-RT, + vs moderate RT and only occlusion	F
48. Anastasilakis, 2014, Greece[3]	Effect of aerobic exercise on **serum** irisin in young adults	Pre-Post	Moderately active young adults (N=20, 10F/10M, age 20)	30-min constant-pace outdoor running.	Before and at the end	↑, no between-sex differences	F
49. Orange, 2022, UK[70]	Effect of aerobic interval exercise on **serum** irisin in overweight/ obese men	Randomized controlled crossover design	Inactive, overweight/ obese men (N=16, 60.0±8.0)	Moderate-intensity aerobic interval cycle ergometer exercise (6 x 5 min at 60% HRR; 2.5 min recovery at 60W). Resting (60 min) control condition.	Before and immediately after	Irisin undetectable	F
50. Kraemer, 2014, USA[53]	Effect of prolonged aerobic exercise on **plasma** irisin in young adults	Counter-balanced cross-over trial	Young adults (N=12) **5F** (23.8±4.7), **7M** (22.7±1.6)	1. Resting trial. 2. 90-min treadmill exercise at 60% of VO_{2max} (women performed the training in two phases of menstrual cycle: a) early follicular (day 3–7), b) mid-luteal phase (day 20–22))	Before, during (54 and 90 min), and 20 min after	**M:** ↑ during exercise, ↔ after **F:** ↑ during exercise, regardless of cycle phase	F

51. Winn, 2017, USA[102]	Effect of different-intensity afternoon exercise on **plasma** irisin in obese women	Randomized counter-balanced cross-over trial	Obese women (N=11, (mean±SEM) 24.3±1.4)	Three protocols (energy-matched exercise): 1. rest 2. MICE: treadmill walking at 55% VO_{2peak} 3. HIIT: 4 min at 80% VO_{2peak}/3 min active recovery at 50% VO_{2peak}	Before and at 30, 50, 80, and 190 min (exercise lasted 10-65 min)	**HIIT:** ↑ during, ↔ after **MICE:** ↑ Peak values at 50 min; =	F
52. Fernandez-del-Valle, 2018, USA[32]	Effects of RT on **serum** irisin	RCT	Healthy adults (N=26, **12F** (21.4±2.5), **14M** (21.2±1.9). **EG** (N=13) **CG** (N=13)	RT: 50-60 min, whole-body training (7 exercises, 3 sets, 10 reps, 70-80% of 1RM per set) CG: rest in the same conditions.	15 min before, during (at 45 min) and immediately after	↔	F
53. Nicolini, 2020, Canada[68]	Effects of HIIT on **serum** irisin in inactive men	NRCT	Healthy sedentary men (N=40). **EG** (N=21, 23±3) **CG** (N=19, 25±4)	HIIT: 5 x 1-min cycling at ~105–125% peak workload; 1.5-min active recovery at 30% peak workload	Before and 30 min after	↔	F
54. Rodziewicz, 2020, Poland[85]	Effect of incremental exercise on **plasma** irisin in master athletes and CG	NRCT	Middle-aged men (N=22): **Highly trained** active endurance trained master athletes (N=12, (mean±SE) 58.6±4.3) **CG** (N=10, 57.4±2.9)	Incremental treadmill exercise until exhaustion (2 km/h every 3 min).	Before and 10 min after	↔ for both groups = before and after	F
55. Tsuchiya, 2018, Japan[97]	Effects of level- and downhill running in healthy men on **plasma** irisin	Pre-Post, two groups	Healthy active men (N=15, 21.6±2.0) Randomized groups: Level-running group (N=8) Downhill-running group (N=7)	30-min treadmill running (duration- and intensity-matched) at 70% VO_{2max} at either 0% or –10% gradient.	Before, immediately after and 1, 3, and 24 h after	↔ group or time effect + 3-h area under the curve in the downhill-running group	F
56. Huh, 2015, Greece[41]	Effects of different types of exercise on **plasma** irisin in persons with and without metabolic syndrome	Randomized counter-balanced cross-over trial, NRCT	Sedentary men (N=20) **Healthy group** (N=14, 41.1±6.7) **Metabolic syndrome group** (N=6, 44.5±8.5)	1.**HIIT**: 5x4 min treadmill walking at 3 km/h alternating with 4x4 min running at 90% HRmax, 36 min total 2.**MICE**: 36 min treadmill walking/running at 65% HRmax 3.**RT**: 45-min whole-body training, 3x8-12 reps at 75–80% of 1RM, six exercises 4. Rest condition	1 hour before the end, immediately after, and 1 hour after	**Immediate:** ↑ all exercise types, + for RT = for all exercise types	F

57. Jóźków, 2019, Poland[46]	Effects of running a marathon on **serum** irisin in middle-aged runners	Pre-post	Middle-aged male runners (N=28, 58±8)	Wroclaw marathon (September, at 22±2°C, 77±13% relative humidity). Mean run time: 04 h:16 min: 02 s ± 0 h:31 min: 23 s.	Before, immediately after and 7 days after	**Immediate and after 7 days:** ↓	F
58. Dror, 2022, USA[29]	Effects of intensity-matched running and cycling on **plasma** irisin in healthy men	Randomized counter-balanced cross-over trial	Healthy adult men (N=13, 23.7±1.0)	30-min running and cycling at 70% HRR	Before, immediately after and 1h after	↑ both exercise modes =	F
59. Ugras, 2022, Turkey[98]	Effect of aerobic exercise on **serum** irisin in young sedentary adults	Pre-Post	Young sedentary adults (N=30, **15F** (21.0±1.1), **15M** (21.1±1.5)	~45-min running at anaerobic threshold (estimated at 60%-70% of HRmax)	Before and immediately after	**Baseline:** + M vs F **After:** ↑ in both sexes	F
60. Ulupinar, 2021, Turkey[99]	Effect of aerobic exercise in different environmental temperatures on **serum** irisin in young adults	Pre-Post	Young healthy adults (N=27, 10F/17M, 20.6±1.8)	40-min running (at 70% HRmax) at three temperatures: 0°C, 12°C, 24°C	Before and immediately after	↑ at 0°C ↔ at 12°C and 24°C	F
61. Bubak, 2017, USA[15]	Effects of exercise in different thermal conditions on **plasma** irisin in active men	Randomized counter-balanced cross-over trial	Active men (N=12, 25±4)	60-min ergometer cycling at 60% W_{max} under three temperature conditions: hot (33°C), cold (7 °C), and room temperature (20 °C).	Before, immediately after, and 3 h after	↔ regardless of the temperature condition =	F
62. Tsuchiya, 2021, Japan[96]	Effects of endurance exercise in different thermal conditions on **plasma** irisin in active men	Randomized counter-balanced cross-over trial	Healthy active men (N=7, (mean±SE): 22.7±0.4)	60-min pedaling (cycle ergometer) at 60% VO_{2max} under three temperature conditions: cold (15–19°C), moderate (24°C), hot (34°C).	Before, during (at 0.5h), immediately after, and 1, 2, and 3 h after	= among the three temperature conditions ↔	F

BDNF = brain-derived neurotrophic factor; BFR = blood-flow restricted; BMI = body mass index; CG = control group; EG = experimental group; ET = endurance training; F = females; FATmax = maximum fat oxidation rate; GXT = graded exercise test; HF = high physical fitness group; HI = high-intensity group; HIIT = high-intensity interval training; HR = heart rate; HRR = heart rate reserve; LF = low physical fitness group; LI = low-intensity group; M = males; MICE = moderate-intensity continuous exercise; NRCT = non-randomized controlled trial; Pre-Post = Pre-Post Study With No Control Group; RCT = randomized controlled trial; RET = combined resistance and endurance training; RPE = rating of perceived exertion; RT = resistance training; SE = standard error; SEM = standard error mean; SIT = sprint interval training; VICE = vigorous-intensity continuous exercise; VO_{2max} = maximal oxygen consumption; vVO_{2max} = maximal speed

↑ significant post-exercise increase in blood irisin

↔ no change between pre-post exercise blood irisin

↓ significant post-exercise decrease in blood irisin

+ significantly superior effect in the intervention group

= no difference between the groups

[a]mean±SD if not otherwise stated

Q = study quality assessment (G = good; F = fair; P = poor)

The characteristics of the studies, including their aim and design, characteristics of the participants and exercise protocols, blood sample and sampling time, results and study quality assessment are presented in Table 1.

Of the 62 studies included in the review, one was performed in Australia [52], one in Brazil[60], eight were performed in Canada[12,22,24,27,61,62,68,83], three in China[36,37,105], two in Estonia[47,48], five in Germany[11,14, 58,82,104], three in Greece[3,40,41], one in Greece and the USA[39], two in Iran[33,66], three in Italy[23,42,64], four in Japan[94-97], one was performed in Mexico[4], one in Norway[69], five were performed in Poland[9,46,85,90,101], two in Spain[63,80], one in Taiwan[93], twelve in Turkey[2,5,10,19,30,31,49,50,71,72,98,99], one in the UK[70], and six in the USA[15,29,32,53,54,102].

By design, four articles reported results of randomized controlled trials (RCT)[14,32,66,105], eight studies were non-randomized controlled studies[31,39,49,61,68,69,85,90], 23 studies were cross-over trials (out of which 13 defined as randomized cross-over trials[2,15,22,27,29,41,42,70,82,94,95,96,102], one defined as exploratory two-group study[62])[9,33,36,37,53,54,63,83,93], 20 studies were pre-post studies (one defined as repeated cross-sectional study[50])[3,5,11,12,19,30,40,46-48,52,58,60,64,72,80,98,99,101], six studies were two-group pre-post studies (one defined as non-randomized uncontrolled study[24])[4,23,71,97,104], one study was a four-group pre-post study[10].

In the majority of studies (N=34) the participants were only men[2,9,10,15,23,24,29,30,36,37,41,42,46,47,49,50,52,54,60-62,64,68-72,83,85,94-97,105], seven studies included only women[4,19,40,48,66,90,102], out of which one study investigated pregnant women[90], and 21 studies included participants of both biological sexes [3,5,11,12,14,22,27,31-33,39,53,58,63,80,82,93,98,99,101,104].

In 47 studies the participants were adults (young to middle-aged).[2,3,5,9,14,15,19,23,27,29,31-33,36,37,40-42,46-50,53,54,60,63,64,66,68,69,71,72,80,82,83,90,94-99,101,102,104,105] Nine studies included older adults[10,11,24,52,61,62,70,85,93], and two of these included veteran athletes[31,85]. Four studies included children and/or adolescents[4,12,22,30], and two studies included both children/adolescents and adults[39,58].

The total number of participants in the analyzed studies was 1,454. The number of participants per study ranged from five[64] (four in a pilot study by Daskalopoulou et al.[27]) to 80[31]. Most of the studies included apparently healthy active or inactive persons, while some included athletes, such as elite taekwondo athletes[5], highly-trained male ultra-endurance athletes[23] and endurance master/middle-aged athletes[46,85], highly-trained female and male rowers[47,48], padel players[80], adolescent handball players[30], black belt judokas[42], veteran athletes of different disciplines (table tennis, running, chess)[10]. Several studies included persons at metabolic risk, such as persons with overweight/obesity[4,12,22,33,58,69,70,102,104], type 2 diabetes[19,61], arterial hypertension[61], and metabolic syndrome[41]. In one study the participants were persons with multiple sclerosis[14], in one study persons with advanced prostate cancer[52], and in one study participants had rheumatoid arthritis[31].

Most studies included exercise trials on treadmills, cycle- or rowing ergometers. In most studies participants performed moderate-intensity continuous exercise (MICE).[2,3,4,12,15,19,22,29,31,37,39,41,47,48,53,58,61-63,69,71,82,83,93-99,102] In eight studies, the participants performed graded-exercise tests.[11,14,27,58,64,82,85,104] In ten studies high-intensity interval trainings were performed[4,22,36,39,41,49,52,68,93,102], and in one study moderate-intensity interval training was performed[70]. Ten studies investigated acute irisin response to resistance training[12,24,32,36,41,54,63,66,95,105], two of which included blood-flow restricted training[24,54]. Three studies included different sprint trainings.[9,83,101] The study that included pregnant women used a combined training.[90] One study compared different types of muscle contractions[50], one study investigated the effect of the whole-body vibration training[40], and one study investigated high-intensity functional training with and without whole-body electromyostimulation[33]. Finally, several studies investigated the effects of training or competition in different sports, such as martial sports – taekwondo[5], judo[42], team sports – soccer[72], handball[30], racquet sports – padel[80], table-tennis[10], and running and endurance sports – 10-km race[60], marathon[46], Ironman and Half-Ironman competition[23], prolonged rowing[47,48].

In 32 studies, irisin was analyzed in the serum[2,3,10,11,14,19,30-33,36,37,40,46,47,52,58,61,62,64,66,68,70,71,82,90,93,94,98,99,104,105], and in 30 studies it was analyzed from plasma[4,5,9,12,15,22-24,27,29,39,41,42,48-50,53,54,60,63,69,72,80,83,85,95-97,101,102]. The blood samples were taken before and up to 72 h after[36,37] the exercise bout.

Thirty-eight studies detected a significant blood irisin increase after at least one type of exercise.[2,3,9,10,12,22-24,27,29,30,33,39-41,48,50,53,54,58,60-62,64,69,71,72,82,83,90,93,95,98,99,101,102,104,105] In 19 studies there was no pre-post exercise difference in the blood irisin level[4,5,11,14,15,19,32,36,37,42,47,52,63,66,68,80,85,96,97]. Four studies detected a post-exercise decrease in the blood irisin[31,46,49,94], and in one study irisin was undetectable in the sample[70].

According to the adopted risk-of-bias criterion, 57 studies were rated as fair, two were rated as having a low risk of bias (good)[4,31], and three as having a higher risk of bias (poor)[23,30,64], mainly because of the specific, narrow studied population[23,30], or a small number of participants[64].

DISCUSSION

The systematic analysis of the articles on acute effects of exercise on circulating irisin, indexed in Web of Science and Scopus, enabled insight into the influence of different aspects of exercise/sports activities and the influence of different characteristics of participants on the acute post-exercise response of blood irisin. Under the *activity-related aspects*, the type of exercise, exercise intensity, sport-specific training or competition activities, and the influence of environmental temperature conditions in which the exercise is performed will be discussed. The discussion on the *participants' characteristics* will include the influence of the participants' age, sex, fitness level and health status on acute post-exercise response of blood irisin.

EXERCISE-RELATED CHARACTERISTICS

Acute effects of endurance exercise on blood irisin levels

Trainings developing different types of endurance were investigated. Four studies investigated the effects of some type of sprint interval training (SIT) on blood irisin levels. Briefly, this type of exercise involves one or more supramaximal sprints, lasting 10 to 30 seconds, separated by passive recovery or active recovery of very low intensity[16]. Bilski et al.[9] found significant effect of SIT on serum irisin levels, whereas one study found the that SIT increased serum irisin level only in women[101]. As a possible explanation for these results, Wiecek et al.[101] cite biological sex differences. In the remaining two studies, SIT failed to induce rise in serum irisin level[49,83], and one study even reported decrease in serum irisin level[49]. As a possible explanation for this, Kabak, Belviranli and Okudan[49] state that maximal intensity of this type of exercise could inhibit the release of irisin from the myocytes. Given that the total number of participants in all these studies was 74, more studies are needed to draw relevant conclusion on the effect of SIT on the serum irisin levels.

Forty-four studies investigated other types of endurance training (ET). In 23 studies a significant post-exercise increase in blood irisin was detected, in 11 of those in men[2,23,29,39,41,60-62,64,69,71], in three in women[48,90,102], and in nine in both biological sexes[3,12,27,53,58,93,98,99,104] The detected increase ranged from slight, but significant change (e.g., in Comassi et al.)[23] up to a 123%-increase in children[58].

In 19 studies some or all types of performed endurance trainings provoked no change in blood irisin. Eleven of these studies were performed on men[15,36,37,47,52,68,83,85,95-97], two on women[4,19], and six on persons of both biological sexes[11,14,22,63,93,104].

In three studies a decrease in circulating irisin was detected after endurance exercise, in two studies in men[46,94] and in one study in women and men[31]. In one study irisin was undetectable[70].

Overall, in the majority of studies, endurance exercise provoked post-exercise increase in irisin to a varying degree. The majority of studies was performed on adult men.

With regard to the type of training, after a continuous moderate-intensity exercise (MICE) an increase was observed in 17 studies[2,3,12,27,29,39,41,48,53,61,62,69,71,82,98,99,102], MICE induced no change in 11 studies[4,15,19,22,37,47,83,93,95-97], and a post-MICE decrease in blood irisin was detected in two studies[31,94].

After a high-intensity interval training (HIIT) an increase was detected in two studies[41,93], and no change was reported in five studies[4,36,52,68,102].

After GXT an increase in circulating irisin was detected in three studies[58,64,104], no change was reported in four studies[11,14,63,85].

Obviously, different factors can influence the effect of exercise, such as exercise modality. Qiu et al.[82] noted a greater rise in serum irisin levels in 60 minutes following a running protocol, in comparison to a cycle ergometer exercise, arguing that running may produce more muscle damage in comparison to cycling[7,91].

Tsai et al.[93] determined the effects of a 30-min continuous and interval endurance training on serum irisin levels in a cross-over design. Interval training significantly increased serum irisin levels, whereas continuous training increased serum irisin levels, but not to the level of statistical significance (p=0,076).[93]

Archundia-Herrera et al.[4] and Moienneia and Hosseini[66] determined the effects of an endurance training session (continuous and interval) and a resistance training session (circuit training). Archundia-Herrera et al.[4] found that interval training significantly increased serum irisin level, whereas continuous did not. A possible explanation for these results could be the low intensity of the continuous training (65% of maximal oxygen reserve).

In conclusion, MICE mostly induced increase in the circulating irisin. The evidence on HIIT and GXT is inconclusive. This concords with the findings of Kazeminasab et al.[51] who found a greater acute effect of aerobic *vs* anaerobic exercise, and the findings of Cosio et al.[26], confirming the positive acute effects of endurance training.

Acute effects of resistance training on blood irisin levels

Twelve studies investigated the effect of different kinds of resistance training on post-exercise blood irisin.[12,24,32,33,36,41,50,54,63,66,95,105]

Tsuchiya et al.[95] found that, when matched for duration, RT caused greater increase in serum irisin than ET and combined endurance and resistance training in young men. Zuo et al[105] found an increase in the serum irisin after both a functional and traditional RT in young sedentary males. Ghalamsiah and Nourshahi[33] also reported an increase after a high-intensity functional training with or without electromyostimulation in overweight adults of both sexes.

Two studies reported results after performing blood-flow restricted resistance training.[24,54] Cordingley et al. [24] reported a significant post-exercise increase in serum irisin in trained older men, 6h post exercise, and Kraemer et al. detected an increase in male students[54].

Huh et al.[41] found that RT provoked a stronger post-exercise serum irisin increase than HIIT and MICE in healthy men as well as men with metabolic syndrome.

Kara et al. found an increase in plasma irisin after concentric, but not isometric training in male athletes[50].

Insignificant post-RT increase in obese adolescents was detected by Blizzard LeBlanc et al.[12] He et al., found no RT effect on serum irisin in inactive young men[36] and Mendez et al.[63] and Fernandez et al.[32] found no post-exercise change in adults of both sexes. Moienneia et al. investigated the effect of high- and low-intensity RT in sedentary young women, and found no post-exercise change after a single training session.[66] However, an 8-week high-intensity resistance training significantly decreased serum irisin level in previously untrained women (p= 0.034), making it possible that, given the participants' prior physical inactivity, exercise increased the sensitivity to irisin.[66,78]

In conclusion, seven studies reported a significant post-RT increase in circulating irisin, six in men[24,41,50,54,95,105], including older men[24] and men with metabolic syndrome[41] and one in both biological sexes[33]. In five studies resistance training did not induce changes in blood irisin, one in adolescents of both sexes[12], one in adult men[36], one in adult women[66]; and two in adult women and men[32,63]. Positive changes in terms of irisin increase were found for concentric contraction exercises[50], RT with electromyostimulation[33] and RT with restricted blood flow[24,54].

Resistance training seems to have a positive acute effect on blood irisin level. More studies on female participants are required and more RCTs are required. The impact of resistance training seems to be more pronounced in its chronic effect on blood irisin, which was recognized as superior to chronic effects of either aerobic or anaerobic exercise.[51] This was recognized especially in older persons, adding to the multiple positive effects of resistance exercise in persons of this age group.[25]

Influence of exercise intensity on acute effects of exercise on blood irisin level

Several studies compared the acute influence of different training intensities on blood irisin level. In the study by Tsai et al.[93] in the middle-aged and older adults HIIT, but not MICE, induced significant post-exercise increase in serum irisin levels. In the study by Tsuchiya et al.[94] there was a significant post-exercise decrease in the serum irisin in sedentary males after the low-intensity exercise, and a greater irisin response after the high-intensity exercise, with an 18% and 23%-increase at 6 h and at 19 h post-exercise, respectively. Archundia-Herrera et al.[4] found no plasma irisin change in overweight/obese adolescent females after neither MICE nor HIIT protocol, arguing that higher intensities might be needed to induce changes. Huh et al.[39] found a larger post-exercise increase in plasma irisin in adolescents after a higher-intensity exercise. On the other hand, Reycraft et al.[83] found no change in plasma irisin after three bouts of different intensity (MICE, VICE (vigorous-intensity continuous exercise), SIT) in 8 male participants. Daskalopoulou et al.[27] found a significant post-exercise increase in plasma irisin, progressive with increasing exercise intensity, with the greatest increase detected after the maximal intensity bout (34%). In that study, exercise caused significant increase in the plasma irisin levels irrespective of intensity - interestingly, just 10 minutes on cycle ergometer at 75 W caused significant rise in plasma irisin levels.[27]

On the other hand, there were no post-exercise changes in the serum irisin after FATmax (maximum fat oxidation rate) and AT (anaerobic threshold intensity) training in the study by He et al.[37] and after long- and short-interval HIITs and RT in He et al.[36] Moienneia et al.[66] found no significant change in the blood irisin after low- and high-intensity resistance training in women. In the study by Colpitts et al.[22] there was an increase in plasma irisin during HIIT training in adolescents, but no post-exercise changes after neither HIIT nor MICE. Winn et al.[102] found that HIIT and MICE induced modest increase in plasma irisin in young obese women, with a rapid (15 min) return to baseline levels after HIIT, and a longer period of return to baseline (>2 h) after MICE. Huh et al.[41] found an increase in plasma irisin regardless of the training intensity (HIIT *vs* MICE).

Out of 12 studies that investigated the effect of exercise bouts of different intensities on changes in blood irisin levels, in five studies an increase in the circulating irisin was detected after a high-intensity exercise in the adolescents, younger and middle aged/older adults.[22,27,39,93,94] In five studies no change was observed in the circulating irisin level, regardless of the exercise intensity[4,36,37,66,83], with Archundia et al.[4] arguing that still higher intensities are needed to provoke the irisin increase. The remaining two studies identified an increase after both HIIT and MICE training.[41,102]

In conclusion, based on the limited number of studies, higher-intensity exercise seems to have a superior potential to induce increase in the circulating irisin. This concords with the evidence from previous studies that have shown that high-intensity interval exercise (at ~85% of peak power output) acutely increased the expression of PGC-1α mRNA in the human skeletal muscle.[56,75] An immediate increase in PGC-1α protein content in the nuclear fractions of human skeletal muscle was also previously detected after a session of sprint-interval cycling training (4 × 30-s 'all-out' sprints), but not after a continuous training (at 63% of the peak power output), suggesting short high-intensity trainings having a superior effect on the acute, early exercise-induced responses.[34]

Acute effects of sport-specific activities on serum irisin levels

Eleven studies determined the effects of either a training session or competition in different sports on circulating irisin levels.[5,10,23,30,42,46-48,60,72,80]

Taekwondo training session did not elicit change in the serum irisin in elite taekwondo athletes[5] and the same was found in black belt judokas after a judo training[42]. Arıkan attributed the failure of a training of high intensity and duration to provoke blood irisin changes to the small sample size (N=13).[5]

Half Ironman induced only slight increase in the serum irisin in highly-trained male ultra-endurance athletes[23], and marathon running induced a decrease in the serum irisin in middle-aged runners[46]. A 10 km self-paced race induced a significant serum irisin increase 24 h after the race in recreational male runners.[60] Prolonged rowing bout induced significant serum irisin increase in highly-trained female, but not male rowers.[47,48] A padel match was of insufficient intensity to induce irisin changes in trained padel players.[80] Despite the fact that the average heart rate of the padel players was 75% of maximal heart rate, the authors failed to observe any increase in the plasma irisin levels, possibly because, even though the padel session lasted 68 minutes, there were only 28 minutes of effective play.[80] Soccer matches induced a significant plasma irisin increase in trained young men[72] while a handball training provoked a significant serum irisin increase in adolescent handball players[30]. In stark difference to most of the studies included in this review, Dündar[30] found that serum irisin levels doubled after the training session, despite the similar duration and number of participants as in the study by Arıkan[5], which makes this result an outlier that must be taken with caution.

Ozcelik et al.[72] attribute the finding of increased plasma irisin to the higher intensity during small-sided games in football, due to more contact with the ball, more passes and more attempts at the target[35].

In the veteran athletes of different disciplines (table tennis, running, chess), only a table tennis match induced a significant increase in the serum irisin.[10]

In conclusion, martial art training sessions were of insufficient intensity to elicit changes in blood irisin.[5,42] Ultra-endurance events induced either a slight increase[23], or even a decrease in the serum irisin[46], while a 10-km race induced a significant blood irisin increase a day after the race[60]. Prolonged rowing increased serum irisin only in female athletes[48]. In investigated racquet sports, a table tennis match induced a significant increase in the serum irisin in veterans[10], while a padel match did not provoke the same changes in younger athletes[80]. The two investigated team sports showed significant serum irisin increase in adolescent handball players[30] and young trained men playing soccer[72].

Different results can certainly be linked to different structure of the training activities in terms of intensity and duration. However, given the small number of studies that determined the effects of playing different sports on the blood irisin levels, more studies are needed to draw conclusions regarding different sports and their effects on circulating irisin levels.

Influence of environmental temperature conditions on acute effects of exercise on blood irisin level

The rationale for investigating combined effect of exercise and different temperature conditions on circulating irisin relies on previous findings that exposure to cold triggers the activation of myokine secretion with the purpose of increasing metabolism of the adipose tissue, especially BAT, as a thermoregulatory mechanism.[45] Also, it was shown that exposure to heat increases blood irisin levels, possibly as a reaction to oxidative stress.[76]

Six studies investigated the influence of environmental conditions (including cold, moderate and hot) on acute effects of exercise on the blood irisin. Ozbay et al.[71] found a small but significant increase in the serum irisin after a moderate continuous running at both cold (−5°C–5°C) and moderate (21°C–25°C) environmental temperature conditions. McCormick et al.[62] investigated the influence of thermal conditions and age on post-exercise serum irisin in adult men, finding significant increase after prolonged exercise in heat stress (WBGT 32°C), regardless of age, with higher levels in young participants. In another study, McCormick et al.[61] investigated the influence of thermal conditions and health status on the serum irisin after the same type of prolonged moderate-intensity exercise in the same environmental conditions as in the previous mentioned study[62], finding a significant irisin increase in the heat-stress conditions in healthy persons, persons with hypertension and persons with type 2 diabetes mellitus, with the increase occurring earlier in the latter two groups. Ulupinar et al.[99] found that continuous moderate exercise at 0°C provoked a 19% increase in the post-exercise serum irisin in young adults, which was not the case for exercise at 12°C and 24°C. On the other hand, Bubak et al.[15] and Tsuchiya et al.[96] found no change in the plasma irisin in young active men after a moderate aerobic exercise in hot, moderate and cold conditions. Interestingly, neither of the last two mentioned studies found an expected irisin increase in cold conditions –at 7°C[15] and at 15-19°C[96], a temperature range that was intentionally chosen not to be low enough to provoke an additional effect of shivering. Interestingly, the study by Huh et al.[40] that used a whole-body vibration exercise to mimic shivering induced a significant blood irisin increase, without cold exposure.

All six studies investigated the effects of continuous moderate-intensity exercise. Two studies[61,62] reported a significant blood irisin increase after exercise in the heat-stress conditions, irrespective of age and health status. Two studies found an increase in the blood irisin in healthy persons after exercise in the cold[71,99], but Ulupinar et al.[99] did not detect the same change at moderate temperature conditions, while two studies[15,96] found no effect of exercise in either hot, moderate, nor cold conditions in young active men. Thus far the number of studies is too small and the results are too heterogeneous to draw firm conclusions on the combined effect of environmental conditions and exercise on blood irisin, which conforms with the results of Jiang et al.[45]

PARTICIPANTS-RELATED CHARACTERISTICS

Influence of age on acute effects of exercise on blood irisin level

In the study by Huh et al.[39] baseline plasma irisin was lower in the older than in the younger men, but post-exercise increase was documented irrespective of age, after a MICE, followed by an exhaustive bout of running. In the study by Cordingley et al.[24], a significant post-exercise increase in the plasma irisin was detected only in older participants, in trained state, 6h after acute resistance exercise. In the study by McCormick et al.[62] there was a significant increase in the serum irisin in younger and older men after prolonged exercise in the heat, but the irisin level was higher in the younger men, at all the time points.

Thus far the number of studies is too small to draw valid conclusions. However, indicative results include lower irisin levels in the older persons, at baseline[39] and at all time points[62], and similar response (increase) of blood irisin after moderate exercise of longer duration either in moderate[39] or hot environmental conditions[62], and an increase only in trained older men after acute resistance training[24].

For the chronic effect, Torabi et al. found that 8-week long exercise protocols, regardless of the type of training, induced significant increase in irisin in the persons younger than 40 years, while the changes were insignificant in the persons older than that age.[92] Cosio et al.[25] found that resistance training protocols of the same duration increased blood irisin, especially in older persons, and in progressive training and higher-intensity training.

The results on the responsiveness of irisin to exercise in older persons are particularly important in the context of mitigating the negative consequences of sarcopenia with advancing age. Namely, beside the well-researched decline in the muscular function, the sarcopenic muscle loss is being increasingly investigated in the context of the systemic effect it brings about by the decreased myokine production – e.g., the adverse effect on the metabolic function, promoting the development of type 2 diabetes mellitus.[73,84]

Influence of sex differences on acute effects of exercise on blood irisin level

Considering possible sex differences, Wiecek et al.[101] found that high-intensity anaerobic exercise increased the plasma irisin levels only in the young female, not male participants. Short intensive exercise in children of both sexes induced significant increase in the serum irisin.[58] Greater and longer-lasting post-exercise serum irisin increase in normal weight women *vs* men after a maximal graded cycle ergometer test was detected by Zügel et al.[104] Kraemer et al.[53] found a transient increase in the plasma irisin during a prolonged aerobic exercise, with no differences between males and females, and irrespective of the menstrual cycle phase in females, but the values decreased toward baseline values shortly after exercise. Ugras et al.[98] detected a higher baseline serum irisin in young males, but a significant increase after a moderate-intensity exercise in both sexes. Arıkan et al.[5] found no effect of exercise on the plasma irisin level in elite taekwondo athletes, after a typical training session, with no difference between the sexes. All the mentioned studies included young adults. In addition, Löffler et al.[58] included lean and obese children and Zügel et al.[104] included obese middle-aged persons.

The limited number of studies that tested the sex differences in response of circulating irisin to exercise employed different types of exercise. Short intensive exercise induced serum irisin increase in both female and male children[58], moderate-intensity exercise provoked transient within-exercise[53] and post-exercise[98] blood irisin increase in both female and male adults. The taekwondo training session induced no changes in the circulating irisin in athletes of both sexes.[5] Sex differences in the blood irisin response were detected only in the studies of Wiecek et al.[101] in which high-intensity exercise provoked irisin increase in females, but not in males, and in the study by Zügel et al.[104] in which the increase was greater and lasted longer in females.

The results on possible sex differences are inconclusive and based on only a few studies, most of which did not detect any. Possible differences indicated by a few studies (e.g., higher baseline blood irisin levels in males[98] and only a female response to high intensity exercise[101]), as well as no difference in the physiological response between the phases of the menstrual cycle in females[53] should be explored in further studies.

In addition, two studies on elite athletes determined the effects of rowing training session on the blood irisin levels in young female[48] and male rowers[47]. Training session induced an increase in the circulating irisin levels in females, but not in males.[47,48] It is interesting to note that the initial blood irisin levels were almost twice as high in males compared to females.[47,48] In comparison with the chronic effects, Torabi et al.[92] found that 8-week programs of different types of training provided significant blood irisin increase in men, but not in women. Cosio et al.[25] found no between-sex differences in the blood irisin after 8-week resistance protocols ($p = 0.17$).

Influence of fitness level on acute effects of exercise on blood irisin level

Six studies compared the acute effect of exercise on the blood irisin level in trained *vs* untrained persons. Qiu et al.[82] found no influence of the training status on post-exercise serum irisin levels (significant increase was detected) in trained and untrained men after a continuous moderate 50-min exercise. In the study by Kabak et al.[49] the baseline plasma irisin was higher in the athletes, but there was a post-exercise decrease, both in the athlete and sedentary group after a HIIT training. In the study by Algul et al.[2], moderate-intensity exercise induced serum irisin increase in both trained and untrained young men. In the study by Huh et al.[39], the baseline plasma irisin was lower in the active *vs* sedentary people, but continuous moderate 45-min running, followed by a run to exhaustion at a near maximal intensity induced irisin increase irrespective of the fitness level. Highly-trained master endurance athletes and inactive middle-aged men showed no significant difference in the baseline plasma irisin and no significant post-incremental exercise change in the same parameter. [85] In the study by Bizjak et al., two groups (high- and low-fitness) of older adults performed a maximal graded exercise, with higher baseline serum irisin in the fitter participants, but no post-exercise changes in either of the groups.[11]

Interestingly, there was no difference in the post-exercise response of the circulating irisin in trained *vs* untrained groups, in all six studies – moderate continuous exercise induced significant increase in both groups in three studies[2,39,82], graded exercise test induced no changes in two studies on middle aged and older persons[11,85], while HIIT induced decrease in the circulating irisin, irrespective of the training status[49]. In two studies the baseline blood irisin values were higher in trained *vs* untrained, in younger[49] and in older[11] participants. In one study[39] baseline irisin values were lower in the active participants, while in the study by Rodziewicz et al.[85] there was no baseline difference related to the fitness level. The results are inconclusive with regard to the baseline values, but seem to indicate that the fitness level does not influence the physiological response of the blood irisin to acute exercise.

Influence of different health problems on acute effects of exercise on blood irisin level

Most studies investigated the acute effect of exercise on the blood irisin level in persons with metabolic disturbances or diseases. Cokar et al.[19] found no change in the serum irisin level after a continuous moderate exercise in women with type 2 diabetes mellitus. Norheim et al.[69] found no significant acute post-exercise effect on the plasma irisin in prediabetic adult men, however, compared to apparently healthy counterparts, prediabetic group had a higher baseline plasma irisin level ($p<0.01$), which is consistent with the current literature[44]. Similar results were found in the study by Zügel et al.[104] – there was a ~30% higher baseline serum irisin in obese compared to lean participants ($p\leq 0.001$), with a post-exercise increase in lean (greater and longer-lasting in women), but not in obese participants. As for the chronic effect, baseline plasma irisin was reduced after a 12-week training program, which could be an indicator of an increased irisin sensitivity.[69] As already mentioned, Perarakis et al.[78] state that "hyperirisinemia" could be a defense mechanism, by which the body attempts to maintain glucose homeostasis. In the mentioned study by Norheim et al. in the euglycemic participants, acute exercise induced significant rise in the serum irisin levels before and after a 12-week training program, whereas in the hyperglycemic group the acute exercise induced a significant rise in the serum irisin levels only when performed after a 12-week training program.[69]

No effect of MICE or HIIT on the post-exercise plasma irisin level were found in the overweight/obese female adolescents[4] and overweight/obese adolescents of both sexes[22]. On the other hand, Blizzard LeBlanc et al.[12] reported an increase in the serum irisin in obese youth after a moderate intensity endurance training. Löffler et al. found a significant rise in the serum irisin level in lean and obese children after a maximal graded exercise test on a cycle ergometer, irrespective of sex and obesity status.[58]

Ghalamsiah et al.[33] reported a significant increase in the serum irisin in overweight adults after a high-intensity functional training, and Löffler et al.[58] reported an increase in obese women after a combined training. Winn et al.[102] found that both MICE and HIIT induced a modest increase in the plasma irisin in obese young women. In the study by Huh et al.[41], there was an increase in the post-exercise plasma irisin in men with metabolic syndrome, regardless of the exercise type (HIIT, MICE, RT), with the strongest effect of RT. In the study by Orange et al.[70], post-exercise serum irisin was undetectable in overweight/obese men. In the study by McCormick et al.[61] there was no post-exercise change in the blood irisin in persons with hypertension or type 2 diabetes after a prolonged exercise in moderate temperature conditions, but a significant increase was detected after the same exercise was performed in the heat-stress condition.

Bernal-Rivas et al. analyzed the studies indexed in PubMed, ScienceDirect, and Medline that investigated the effect of exercise on irisin in persons with overweight and/or obesity, type 2 diabetes and/or impaired glucose tolerance.[8] Out of 13 studies that measured serum/plasma irisin, only six detected significant post-exercise irisin increases. The authors attribute the heterogeneity of the results among the studies to different factors related either to the participants (age, level of fitness), exercise type, or methodology (type of sample (serum, plasma) or sampling time frame), emphasizing the need for a broader, more integrative approach in answering this research question.[8]

Vecchiato et al. suggested high-intensity training intervention as preferred to increase irisin in the patients with type 2 diabetes[100], and Torabi et al.[92] concluded the same for the high-intensity interval training in overweight and obese adults. The mentioned two studies analyzed the investigations of the exercise interventions of longer duration. Based on the studies analyzed in this review, we cannot draw sound conclusions on the preferred exercise type for acute effects.

Regarding other health disorders, Briken et al.[14] found insignificant post-graded exercise changes in the serum irisin in persons with multiple sclerosis. Kim et al.[52]

reported no post-HIIT change in the serum irisin level in persons with advanced prostate cancer. Interestingly, Ercan et al.[31] found a decrease in the serum irisin in persons with rheumatoid arthritis after a moderate continuous exercise bout.

In conclusion, four studies reported increased circulating irisin in overweight/obese adolescents and/or adults after different types of exercise[12,33,58,102], one study reported such increase in persons with metabolic syndrome[41], and one in persons with hypertension or type 2 diabetes after exercise in the heat[61]. In seven studies there was no post-exercise change in the blood irisin in prediabetic participants[69], overweight/obese adolescents or adults[4,22,104], women with type 2 diabetes[19], persons with multiple sclerosis[14] and persons with prostate cancer[52]. In persons with rheumatoid arthritis there was a post-exercise decrease in the blood irisin.[31]

There are a few limitations of the analyzed studies and of this review. First, there is a potential problem of measuring and detecting irisin in the serum/plasma, as Albrecht et al.[1] state that detection of irisin in the serum might be a product of cross-reaction with some other non-specific serum protein, not irisin itself. The need for more robust methods for laboratory irisin detection were also put forward by other authors. [25,43] Secondly, diurnal variations in the blood irisin levels might influence circulating irisin levels after exercise. Tsuchiya et al.[95] determined the diurnal levels of the serum irisin in the period of 12 hours (from 8 AM to PM). On average, there were no statistically significant differences at any time point, but there was a variation up to 100ng/mL at different time points. This small difference could affect statistical significance in the blood irisin levels after exercise. Thirdly, it is well established that obese individuals have higher initial circulating irisin levels compared to lean individuals[44], but it is unknown whether there are differences in the initial blood irisin levels between men and women, and how these differences affect serum/plasma irisin response after exercise. Additionally, the effect of lean mass on blood irisin levels is still unknown. With regard to research design and methodology, analyzed studies are rather diverse and the majority had some degree of the risk of bias. The strength of the review includes encompassing different activity- or participants-related aspects of acute exercise effects on the blood irisin, although there are still not enough studies to draw firm conclusions on each of those aspects. The limitations of this review include analyzing only two databases and the lack of statistical synthesis of the results.

CONCLUSION

The acute effects of different kinds of exercise and participants characteristics on the circulating irisin levels are still insufficiently elucidated. To review the literature, we searched Scopus and Web of Science databases, identifying 62 articles on different aspects of acute effects of exercise on blood irisin in humans. Most studies included adult male participants and conducted some kind of endurance protocol (continuous or interval). Small number of studies determined the effects of strength training and playing different sports on blood irisin levels.

In conclusion, endurance protocols increase blood irisin levels significantly, at least at some time points after exercise. Resistance training also tends to have a positive acute effect on the blood irisin level. Protocols of higher intensity tend to have a greater potential to increase blood irisin compared to less intensive protocols. Thus far no valid conclusion can be drawn on the combined effect of environmental conditions and exercise on blood irisin due to a small number of heterogeneous studies. Age, sex, and fitness level of participants do not seem to affect the physiological response of blood irisin to acute exercise. Most studies on participants with health problems investigated the acute effect of exercise on the blood irisin level in persons with metabolic disturbances with an indication of positive, but still inconclusive results.

Future studies should aim to determine the optimal exercise intensity to induce maximal irisin increase. More studies on the combined effects of exercise and environmental conditions are needed. Finally, females are underrepresented, especially in the studies on strength training.

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