Review article

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Effects of Hyperbaric Oxygen Therapy on Recovery and Physical Performance: a Systematic Review

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Effects of Hyperbaric Oxygen Therapy on Recovery and Physical Performance: a Systematic Review

Abstract

The potential mechanisms underlying the improvement in physical performance with hyperbaric oxygen therapy (HBOT) are multifaceted and not yet fully understood. Therefore, the aim of this systematic review was to identify and summarize the relevant literature on the influence of HBOT on recovery and performance. To identify potential studies, a comprehensive search was performed in two electronic databases: PubMed and MEDLINE. We identified 13 relevant studies, with the total of 271 participants. Total male participants were 249, while female were 22. The studies on post-exercise recovery suggest that hyperbaric oxygen therapy may have positive effects on various recovery parameters, including reduced lactate concentration, improved heart rate recovery, enhanced antioxidant capacity, and accelerated recuperation. The studies on HBOT effects on physical performance provide some intriguing insights. While most studies indicate the potential for hyperbaric oxygen therapy to influence physical performance positively, it's crucial to consider that the effectiveness of HBOT can vary based on factors like exercise type, intensity, and individual athlete characteristics. the use of HBOT for recovery and performance is a promising field, but further research is required to establish standardized protocols and to better understand the specific conditions under which hyperbaric oxygen therapy can be most beneficial.

Key words: recovery, performance, oxygen, athletes

Pregledni rad

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Uticaj hiperbarične komore na oporavak i performanse: pregledni rad

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Sažetak

Potencijalni mehanizmi koji leže u osnovi poboljšanja fizičkih performansi hiperbaričnom terapijom su višestruki i još uvek nisu u potpunosti shvaćeni. Stoga je cilj ovog sistematskog pregleda bio da se identifikuje i sumira relevantna literatura o uticaju terapije hiperbaričnom komorom na oporavak i performanse. Da bi se identifikovale potencijalne studije, izvršena je sveobuhvatna pretraga u dve elektronske baze podataka: PubMed i MEDLINE. Identifikovali smo 13 relevantnih studija, sa ukupno 271 učesnikom. Ukupan broj muških učesnika je bio 249, dok je žena bilo 22. Studije o oporavku nakon vežbanja sugerišu da hiperbarična terapija kiseonikom može imati pozitivne efekte na različite parametre oporavka, uključujući smanjenu koncentraciju laktata, poboljšani oporavak otkucaja srca, povećan antioksidativni kapacitet i ubrzanu rekuperaciju. Studije o efektima hiperbarične komore na fizičke performanse pružaju različite uvide. Dok većina studija ukazuje na potencijal hiperbarične terapije kiseonikom da pozitivno utiče na fizičke performanse, ključno je uzeti u obzir da efikasnost hiperbarične komore može da varira u zavisnosti od faktora kao što su tip vežbanja, intenzitet i individualne karakteristike sportiste. Upotreba hiperbarične komore za oporavak i performanse je polje koje obećava, ali su potrebna dalja istraživanja da bi se uspostavili standardizovani protokoli i da bi se bolje razumeli specifični uslovi pod kojima hiperbarična terapija kiseonikom može biti najkorisnija.

Ključne reči: oporavak, performance, kiseonik, sportisti

Introduction

Hyperbaric oxygen therapy (HBOT) is a treatment in which 100% oxygen is supplied under elevated pressure. Such treatment increases dissolved oxygen levels in the blood and results in high partial pressure of oxygen in peripheral tissues, which is beneficial for conditions associated with low O2 environments, such as carbon monoxide poisoning, decompression sickness, arterial gas embolism, and tissue oxygen deprivation due to radiation-induced tissue damage (Bennett et al., 2005; Tibbles & Edelsberg, 1996). HBOT is also a safe, effective, and non-invasive method for treating various conditions (Kaur et al., 2012).

Athlete recovery after training is a constant concern for coaches, as inadequate recovery can lead to chronic fatigue, decreased performance, and increased risk of injury (Reilly & Ekblom, 2005). In sports injuries, soft tissues, including muscles, ligaments, and tendons, are often damaged by oxygen deprivation due to edema or haemorrhage in the injured tissue. Similarly, HBOT has become a recommended treatment for healing injuries in non-athletes (Mortensen, 2008; Tiidus, 2015). In this context, the main function of this treatment is to accelerate the healing of soft tissues by reducing local hypoxia, inflammation, and edema (Mayer et al., 2005), and it may be beneficial for healing knee or ankle ligament injuries, joint sprains, or muscle injuries (J. Staples & Clement, 1996). HBOT has been reported to accelerate cell regeneration and tissue repair, which should help eliminate fatigue and restore endurance. It has gained considerable attention among sports medicine practitioners as a supportive therapy to accelerate recovery from muscle injury in athletes, but its exact efficacy remains unclear (Horie et al., 2014; Ishii et al., 2005; Serlin et al., 1995; J. R. Staples et al., 1999).

There are fewer studies in the literature on the use of HBOT in high performance athletes. Ishii et al (2005) reported the use of HBOT as a recovery method for muscle fatigue during the Nagano Winter Olympics. It was found that all athletes benefited from HBOT treatment and recovered faster. In addition, Haapaniemi et al. (1995) and Fischer et al. (1988) indicated that lactic acid and ammonia were cleared more rapidly by HBOT treatment, resulting in a shorter recovery time. Staples et al. (1999) investigated whether intermittent HBOT treatment improved recovery from delayed-onset muscle soreness (DOMS) of the quadriceps in 66 untrained men. The results suggest that treatment with HBOT can improve recovery, but this study had a complex protocol and the experimental design was not entirely clear (exclusion of some participants and group assignment was not clarified), making interpretation very difficult. Therefore, the aim of this systematic review is to identify and summarize the relevant literature on the influence of hyperbaric chamber therapy on recovery and performance.

Materials and Methods

This systematic review was conducted according to the Preferred Reporting in Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021).

Eligibility Criteria

The inclusion criteria were published studies in English, male or female adults, and the HBOT was conducted as an experimental program. In addition, no inclusion criteria were applied regarding participants' baseline fitness level or sport experience.

Search Strategy

To identify potential studies, a comprehensive search was performed in two electronic databases: PubMed and MEDLINE (Ovid), limiting the search to the following keywords: “oxygen”, "treatment", "hyperbaric therapy", “hyperbaric oxygenation”, "recovery", “performance” and "muscle injury". When available, we used medical subject heading (mesh) terms. We used the Boolean operators "OR" and "AND" to combine terms. A descriptive method was used to analyze the data obtained. All titles and abstracts were reviewed for potential papers to be included in the systematic review. In addition, we performed a backward and forward search by searching the references and citations of the included studies. Reference lists of previous reviews were also reviewed. Relevant studies were selected after thorough review if they met the inclusion criteria. Figure 1 shows the flow diagram.

Study Selection and Data Collection

Duplicate review was performed using EndNote X9, and all articles were screened using the Rayyan app (Ouzzani et al., 2016). Two reviewers (GD and NT) independently reviewed titles and abstracts using the aforementioned app. All included articles were subjected to quality assessment.

Risk of Bias Assessment

The quality of included studies was assessed using the Cochrane Collaboration's revised risk-of-bias tool (Higgins et al., 2019). The following biases were assessed: bias due to the randomization process, bias due to deviations from planned interventions, bias due to missing outcome data, bias in outcome measurement, bias in selection of reported outcomes, and overall bias. The risk of bias was rated as low, somewhat concerning, or high for each domain and for overall bias.

Results

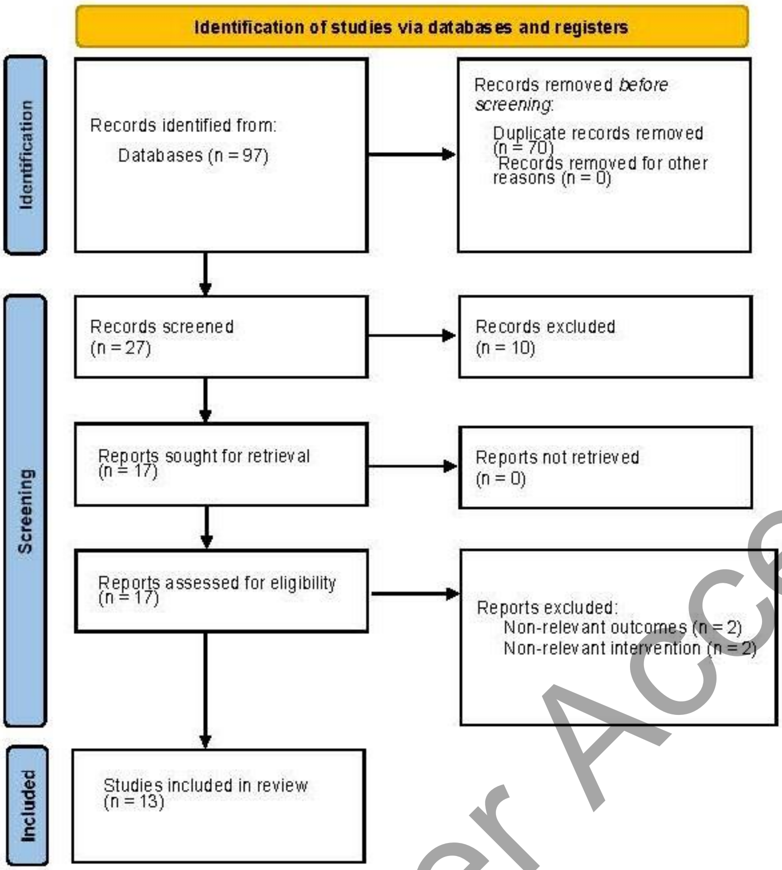
Study Selection

A detailed overview of the process of collecting adequate studies is shown in Figure 1. The automation tools used in the databases were language (English) and type of publication (academic journals). Duplicate entries were removed after combining the results of the search strategy. Titles and abstracts were screened to identify studies that used hyperbaric therapy to promote muscle recovery or muscle performance. The full texts of these articles were read to determine if the inclusion criteria were fully met. All studies that met the inclusion criteria were rescreened to determine if they were eligible for the systematic literature review.

After a general search of the database, 97 relevant studies were identified. Based on titles and duplicates, 80 studies were excluded, with additional and 7 studies, because they were written in a language other than English. A total of 13 studies met the defined criteria and entered in the systematic review.

In the final analysis, 13 relevant studies were included in the systematic review, based on the early defined criteria, published studies in English language in the period from 1999 to 2021, the sample of participants had to be both male and female adults with the primary result obtained for the purposes of systematic examinations was conducted hyperbaric chamber as an experimental program.

Figure 1. PRISMA flow diagram.



Characteristic of the Included Studies

We identified 13 relevant studies, with the total of 271 participants. Total male participants were 249, while female were 22. The highest number of participants was 60 (Sueblinvong et al., 2004) and the lowest was 10 (Park et al, 2018; Hodges et al, 2002). Only Babul et al., (2003) had female participants, while the rest of the studies had male participants, while mixed gender studies were only in one research (McGavok et al, 1999). The atmosphere of absolute pressure was in most of the studies 2.5 ATA (McGavok et al, 1999; Mekjavic et al, 2000; Webster et al, 2002; Hodges et al, 2002; Sueblinvong et al, 2004; Shimonda et al, 2015, Chen et al, 2019; Woo et al. 2022). The rest of the studies used 2.0 ATA (Babul et al, 2003; Hadanny et al, 2022) and 1.3 ATA (Park et al, 2018; Mihailović et al, 2023). Also, the longest time spended in the chamber was 100 minutes (Chen et al, 2019), while the shortest was 30 minutes (Sueblinvong et al., 2004; Park et al, 2018).

Table 1 about here

Table 1. Studies included for analysis

Study	Characteristics of the sample of the participants				Intervention protocol	Intervention characteristics		Outcomes
	Sample size, n (F)	Groups	Age (y)	Sport		EG	CON	
McGavok et al. (1999)	12 (6 F)	/	M - 29.5 ± 4.0 F - 23.5 ± 3.5	Trained runners	90 min treadmill run at 75–80% VȮ2max	95% O_2 at 2.5 ATA for 90 minutes	NN for 90 minutes	VO2max ↔
Mekjavic et al. (2000)	24	EG - 12 CON - 12	20-35	Healthy participants	Maximal isometric strength	100 O_2 concetration at 2.5 ATA for 60 minutes	NN at 0.2 ATA for 60 minutes	DOMS ↔ Elbow flexor max iso strength ↔
Webster et al. (2002)	12	EG – 6 CON - 6	24.2 ± 3.2	Healthy participants	Strenuous eccentric exercise	100% O_2 concetration at 2.5 ATA for 60 minutes	NN at 1.3 ATA for 60 minutes	IMPT ↔ PIT ↑* (HBOT) Pain sensation and unpleasantness ↑* (HBOT)
Hodges et al. (2002)	10	/	25.7 ± 5.5	Moderately trained participants	Maximal incremetal test for assessing VO_2max	95% O_2 at 2.5 ATA for 90 minutes	/	BLA ↔ VO_2max ↔ Run time (min) ↔ HRmax ↔
Sueblinvong et al. (2004)	60	RR – 20 HBOT – 20 OR – 20	21+2 21+2 21+2	Naval cadets, fitness levels similar to professional athletes	Incremental test on cycle ergometer	100% O_2 concetration at 2.5 ATA for 30 minutes	RR – passive rest OR - O_2 inhalation	BLA ↓* (HBOT)
Babul et al. (2003)	16 (F)	EG – 8 CON - 8	25.25 ± 4.1 25.49 ± 4.24	Sedentary female	300 eccentric contractions of the non-dominant leg	100% O_2 concetration at 2.0 ATA for 60 minutes	21% O_2 at 1.2 ATA for 60 minutes	PMS ↔ IS ↔ CK ↔
Shimonda et al. (2015)	20	EG – 10 CON - 10	22.0 ± 1.1 21.9 ± 0.7	Healthy participants	Maximal isometric plantar flexion intermittently - a 2-second contraction followed by a 2-second rest x 50	100% O_2 concetration at 2.5 ATA for 60 minutes	NN at 1.2 ATA for 70 minutes	Force production ↑* (EG)
Branco et al. (2016)	11	/	29. 7± 6.6	Jiu-jitsu athletes	Jiu-jitsu intense training sessions	100% O_2 concetration at 2.39 ATA for 89 minutes	NN for 90 minutes	BLA ↔ RPE ↔ RPR ↑* Cortisol ↔ Testosterone ↔ CK ↔ ALT ↔ AST ↔ LDH ↔

Park et al. (2018)	10	PRT PST CON	21.10 ± 1.25	Amateur football players	Maximal exercise load test on treadmill (Bruce protocol)	30% O_2 concetration at 1.3 ATA for 30 min	/	BLA ↓* (POT) HR (bpm) ↓* (POT) BAP ↔
Chen et al. (2019)	41	EG -20 CON - 21	23.9 ± 5.1 26.3 ± 5.6	Professional baseball athletes	Intensive training sessions	100 O_2 concetration at 2.5 ATA for 100 minutes	NN at 1.3 ATA for 100 minutes	CK ↓* (EG) MB ↓* (EG) GOT ↓* (EG) Pain intensity and interference ↓* (EG)
Woo et al. (2022)	12	EG – 6 CON – 6			Maximal incremental test, Bruce protocol	100% O_2 concetration at 2.5 ATA for 60 minutes	NN for 60 minutes	BAP CK ↓* (EG) LDH ↓* (EG)
Hadanny et al. (2022)	31	EG – 16 CON 15	40-50	Master athletes	Maximal incremental test on cycle ergometer	100 O_2 concetration at 2.0 ATA for 60 minutes	1.02 ATA for 60 minutes	VO2max ↑* (EG) VO2at ↑* (EG) BLA ↔
Mihailović et al. (2023)	12	/	NA	Professional cyclists	Fatiguing exercise for 10 minutes (consisting of two steps of 5 minutes at 80% and 90% of MAP) and 5-minute maximal cycling effort after the HBOT	100% O_2 concetration at 1.3 ATA for 75 minutes	/	RPE ↓* HRV ↑* Power (W) ↑*

Legend: **F** – female; **EG** – experimental group; **CON** – control group; **RR** – rest recovery; **OR** – oxygen recovery; **HBOT** – hyperbaric oxygen therapy; **PRT** – pre-treatment; **PST** – post-treatment; **VO_2max** – maximal oxygen uptake; **ATA** – absolute atmosphere; **NN** – normoxic normobaric; **DOMS** – delayed onset muscle soreness; **IMPT** – isometric muscle peak torque; **PIT** – peak isometric torque; **BLA** – blood lactate; **IS** – isometric strength; **CK** – creatin cinase; **LDH** – lactate dehydrogenase; **RPE** – rate of perceived extraction; **RPR** – rate of perceived recovery; **BAP** – biological antioxidant potential; **ALT** – alanine aminotransferase; **AST** – aspartate aminotransferase; **MB** – myoglobin; **GOT** – glutamic oxaloacetate transaminase; **HRV** – heart rate variability

Effects of HBOT on Recovery

The studies on post-exercise recovery suggest that hyperbaric oxygen therapy may have positive effects on various recovery parameters, including reduced lactate concentration, improved heart rate recovery, enhanced antioxidant capacity, and accelerated recuperation. Branco et al. (2016) investigating the effects of HBOT on post-training recovery in jiu-jitsu athletes suggested that HBOT could enhance post-training recovery processes in athletes, potentially reducing the time required for recuperation. Most recent study (Mihailovic et al, 2023) highlighted the potential benefits of post-exercise hyperbaric oxygenation on improving recovery for subsequent performance. Earlier study (Park et al, 2018) examined the effects of low-pressure hyperbaric oxygen treatment before and after maximal exercise on various recovery indicators, including lactate concentration, heart rate recovery, and antioxidant capacity. It indicated that HBOT could positively influence post-exercise recovery. Furthermore, Sueblinvong et al. (2004) investigated the relationship between hyperbaric oxygenation and blood lactate clearance in naval cadets, highlighting the potential of HBOT to aid in post-exercise recovery.

Effects of HBOT on Performance

There are contraversal results regarding the performance. While some of the studies showed the potential for HBOT to influence physical performance positively, others didn't found significant effects. This is mainly due to difference in participants, exercise type, intensity, and individual participants characteristics. Hadanny et al. (2022) showed that HBOT had positive effects on mitochondrial respiration and physical performance in middle-aged athletes, suggesting a potential role in enhancing physical performance. Shimoda et al. (2015) suggested that HBOT could reduce muscle fatigue after intermittent exercise, potentially enhancing physical performance during high-intensity intermittent activities. Additionally, Sueblinvong et al. (2004) found improved lactate clearance that could contribute to enhanced physical performance capacity. Woo et al. (2020) hinted at potential impacts on physical performance recovery after intense exercise, specifically in terms of reducing inflammation and muscle damage.

Discussion

The effects of hyperbaric chambers on recovery and performance are a topic of ongoing research with mixed results. The present study aims to identify and summarize relevant literature on hyperbaric oxygen therapy effects on performance and recovery. The main finding of this systematic review are that some studies show positive outcomes in terms of recovery and performance enhancement, while others did not find significant benefits. It is important to consider that the outcomes may vary based on factors such as the type of sport, the condition being treated, and the specific protocols used in the hyperbaric chamber. The mechanisms behind the potential benefits of hyperbaric oxygen therapy may involve improved tissue oxygenation, reduced inflammation, and enhanced recovery processes.

Effects of HBOT on Recovery

Collectively, these studies suggest that hyperbaric oxygen therapy may have a positive impact on recovery from soft tissue injuries, exercise-induced muscle damage, and post-training fatigue. However, the effectiveness of HBOT for recovery may depend on the specific injury or condition and the individual athlete. Studies on the effects of hyperbaric oxygen therapy on muscle damage provide mixed results. While some research, such as Webster et al. (2002) and Shimoda et al. (2015), suggests that HBOT may have positive effects on mitigating muscle damage and reducing fatigue, others, like Mekjavic et al. (1999), did not find significant benefits for recovery from delayed onset muscle soreness. Additionally, Woo et al. (2020) highlighted the potential for hyperbaric oxygen therapy to improve muscle recovery following intense exercise.

The enhanced recovery observed with hyperbaric oxygen therapy (HBOT) can be attributed to several potential mechanisms. HBOT exposes the body to increased atmospheric pressure, which results in higher oxygen levels being dissolved in the bloodstream. This enriched oxygen supply can promote more efficient oxygen delivery to tissues, aiding in the repair of damaged cells and tissues. HBOT has anti-inflammatory effects. By decreasing inflammation, it can help reduce the extent of swelling and pain associated with injuries or muscle damage, thereby expediting the healing process. Moreover, HBOT may stimulate the production of growth factors and enhance collagen formation. This can lead to more rapid tissue repair, benefiting athletes recovering from soft tissue injuries. Furthermore, the elevated oxygen levels and increased pressure associated with HBOT can improve blood flow. Enhanced blood circulation can transport vital nutrients and oxygen to damaged tissues and facilitate the removal of waste products. Improved oxygen delivery and circulation can help the body eliminate metabolic waste products more efficiently, potentially reducing post-exercise soreness and fatigue.

The results from these studies suggest that the effectiveness of hyperbaric oxygen therapy in mitigating muscle damage may depend on factors such as the type of muscle damage, exercise intensity, and specific HBOT protocols. Further research is needed to determine the optimal conditions and protocols for athletes seeking to utilize HBOT as a recovery strategy for muscle damage.

Overall Discussion on Performance

The studies on HBOT effects on physical performance provide some intriguing insights. Research, such as Hadanny et al. (2022) and Shimoda et al. (2015), suggests that HBOT might have positive effects on physical performance, potentially through mechanisms like reduced fatigue and enhanced mitochondrial respiration. Sueblinvong et al. (2004) indirectly implies that improved lactate clearance may contribute to enhanced physical performance. Additionally, Woo et al. (2020) pointed to potential benefits for physical performance recovery after intense exercise.

The potential mechanisms underlying the improvement in physical performance with HBOT are multifaceted and not yet fully understood. However, several mechanisms have been proposed based on existing research. One of the primary effects of HBOT is the delivery of higher concentrations of oxygen to tissues and cells. This enhanced oxygen availability can lead to improved aerobic and anaerobic energy production during exercise. The increased oxygen supply to muscles may delay the onset of fatigue and improve endurance. Additionally, HBOT has been suggested to reduce muscle fatigue and improve muscle function. The increased oxygen levels can help remove metabolic waste products such as lactic acid more efficiently, potentially delaying the onset of muscle fatigue and allowing athletes to maintain higher levels of exertion for longer periods. Furthermore, improved recovery after intense exercise is another mechanism. HBOT may reduce post-exercise muscle soreness and inflammation, allowing athletes to recover more quickly between training sessions or competitions. This can contribute to better overall physical performance. One more possible mechanism is through improved cellular function. HBOT may enhance mitochondrial function and increase ATP (adenosine triphosphate) production, which is critical for cellular energy. This can result in better overall energy levels, potentially improving physical performance.

While most studies indicate the potential for hyperbaric oxygen therapy to influence physical performance positively, it's crucial to consider that the effectiveness of HBOT can vary based on factors like exercise type, intensity, and individual athlete characteristics. Athletes and sports professionals should carefully assess the relevance of HBOT to their specific physical performance needs and consult with experts to make informed decisions. Further research may be required to refine and validate its use for enhancing physical performance.

Study limitations

The main limitations of the study lies in a small sample of participants through the studies. Moreover, we didn’t separated the effects of a single sessions and the effects of several sessions. Furthermore, the participants were athletes but also non athletes. Therefore, more research is needed to determine the optimal conditions and protocols for athletes to maximize the benefits of hyperbaric chambers in their training and recovery strategies.

Conclusion

Based on identified relevant studies, most of them showed improvements in performance and recovery. However, there are some studies that showed no effects of hyperbaric chamber. In conclusion, the use of HBOT for recovery and performance is a promising field, but further research is required to establish standardized protocols and to better understand the specific conditions under which hyperbaric oxygen therapy can be most beneficial. Athletes and sports professionals should consider consulting with experts in the field to determine whether hyperbaric oxygen therapy is a suitable and effective option for their individual needs.

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