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The effects of photobiomodulation (red light therapy) on delayed onset muscle soreness (DOMS) and muscle recovery in adults: a narrative review

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Abstract

Background. Photobiomodulation (PBM) has gained attention as a potential non-invasive strategy to enhance muscle recovery following exercise-induced muscle damage. However, its effectiveness remains inconsistent across studies in human trials.

Objective. The aim of this review was to critically evaluate the effects of PBM on delayed onset muscle soreness (DOMS), functional muscle recovery, and biochemical markers of muscle damage in humans.

Methods. A narrative review of recent studies investigating PBM in the context of exercise-induced muscle damage was conducted. Relevant articles were identified through electronic databases and analysed qualitatively.

Results. Most studies suggest that PBM may reduce DOMS, improve recovery of muscle function, and attenuate biochemical markers such as creatine kinase. Mechanistic evidence supports enhanced mitochondrial activity, increased ATP production, and modulation of oxidative stress and inflammation as potential pathways for these effects. However, some studies reported no significant benefits, reflecting variability in PBM parameters, timing of application, exercise modalities, and participant characteristics.

Conclusion. PBM shows promise as a supportive recovery strategy for athletes and physically active individuals, particularly in contexts requiring rapid post-exercise recovery. Nevertheless, standardized treatment protocols and further high-quality studies are necessary to confirm its efficacy and determine optimal application parameters.

Keywords: Photobiomodulation, Red light therapy, Delayed onset muscle soreness, Muscle recovery, Exercise-induced muscle damage, ATP, Mitochondrial function, Phototherapy, Exercise recovery

1. Introduction

Delayed onset muscle soreness (DOMS) is a physiological phenomenon associated with intense physical activity. Although DOMS is generally considered a mild form of muscle injury, it represents one of the main factors contributing to reduced athletic performance. Over the past decades, several theories have been proposed to explain its etiology. Currently, the most widely accepted mechanism involves ultrastructural damage to muscle fibers caused by unaccustomed or excessive exercise, leading to protein degradation, apoptosis, and a localized inflammatory response. Clinical symptoms such as muscle pain, stiffness, and reduced force production typically occur within 24–72 hours after exercise (Hotfiel et al., 2018). Traditional strategies used to alleviate DOMS include rest, stretching, and cryotherapy; however, their effectiveness remains limited (Wiecha et al., 2024).

PBM has been increasingly applied in sports performance, physiotherapy, and rehabilitation, owing to its potential to accelerate recovery and reduce muscle soreness. Photobiomodulation (PBM) is a non-invasive therapeutic approach that utilizes red or near-infrared light, typically in the range of approximately 600–1100 nm, to elicit biological effects in tissues. PBM is also referred to in the literature as low-level laser therapy (LLLT), low-level light therapy, red light therapy or phototherapy, reflecting minor variations in device type and wavelength used (Freitas et al., 2016). One of the primary mechanisms of PBM involves the interaction of light with mitochondrial chromophores, particularly cytochrome c oxidase, a key enzyme in the

mitochondrial respiratory chain (Karu, 2010). Absorption of photons by cytochrome c oxidase enhances electron transport and mitochondrial membrane potential, leading to increased ATP synthesis, modulation of reactive oxygen species (ROS), and improved cellular redox signaling (Byrnes et al., 2015; Hamblin, 2016). These changes can activate multiple metabolic and signaling pathways, including nitric oxide signaling, which further contribute to improved cellular energy metabolism and reduced oxidative stress (Dompe et al., 2020). In addition, PBM may influence ion channels and stimulate the release of nitric oxide (NO), resulting in vasodilation, improved blood flow, and enhanced delivery of nutrients, as well as more efficient removal of metabolic by-products from tissues (Hamblin, 2018).

Due to these mechanisms, PBM may represent a valuable supportive strategy for athletes, particularly during periods of intensive training or competition when rapid recovery is essential. The application of PBM has been suggested to reduce subjective muscle soreness and accelerate the restoration of muscle strength and performance following exercise. By improving microcirculation and cellular metabolism, PBM may facilitate faster recovery processes. Therefore, red and near-infrared light therapy may be beneficial in both strength and endurance training, as well as in sports requiring rapid recovery between training sessions or competitions (Ferraresi et al., 2016).

Therefore, the aim of this study was to review the current evidence regarding the effects of photobiomodulation on delayed onset muscle soreness and muscle recovery in adults.

2. Research materials and methods

A narrative review of the literature was conducted to assess the effects of photobiomodulation (PBM) on exercise-induced muscle damage and recovery. Relevant studies were identified through electronic databases, including PubMed and Google Scholar.

The search strategy employed combinations of the following keywords: “photobiomodulation,” “red light therapy,” “muscle recovery,” “delayed onset muscle soreness,” and “exercise-induced muscle damage.”

Eligible studies were published in English and involved human participants. Both randomized controlled trials and experimental studies investigating the effects of PBM on muscle soreness, functional recovery, or biochemical markers were included.

Studies focusing on unrelated interventions or lacking relevant outcome measures were excluded. The selected articles were analyzed qualitatively, and their findings were synthesized narratively.

3. Research results

3.1 Effects on Delayed Onset Muscle Soreness (DOMS)

Photobiomodulation (PBM) has been extensively investigated as a non-invasive modality for alleviating delayed onset muscle soreness following resistance and eccentric exercise. Several clinical and experimental studies have documented a reduction in subjective muscle soreness in participants treated with PBM compared to placebo or control conditions. For example, Leal-Junior et al. (2010) and Ferraresi et al. (2016) reported that individuals receiving PBM experienced lower perceived soreness in the 24–72 hours following exercise, suggesting that light therapy may influence the physiological processes underlying post-exercise discomfort. Integrated mechanistic evidence further supports this observation, indicating that PBM interacts with mitochondrial chromophores, particularly cytochrome c oxidase, leading to enhanced ATP production and modulation of reactive oxygen species, which together may contribute to reduced nociceptive signaling and pain perception (Upadhyay et al., 2025). Furthermore, higher-level evidence supports these findings. A recent systematic review and meta-analysis by Tsou et al. (2025) reported that PBM was associated with a moderate reduction in perceived muscle soreness and improvements in muscle strength within 24–96 hours after exercise, suggesting a clinically relevant effect on post-exercise recovery.

Data from De Marchi et al. (2017) complement these findings through a randomized controlled comparison of different light sources. In this trial, pulsed low-level laser combined with light-emitting diodes (LEDs) produced greater reductions in DOMS than continuous laser or sham conditions, accompanied by better preservation of maximal voluntary contraction and lower creatine kinase levels. These results underscore the importance of PBM parameters such as pulsing and wavelength choice in determining clinical outcomes. Similarly, Antonialli et al. (2014) demonstrated that combined super-pulsed laser and LED phototherapy could attenuate DOMS and support inflammatory resolution, highlighting that synergistic use of multiple light sources may enhance tissue repair processes.

Some studies have assessed PBM administered before exercise and its influence on subsequent DOMS symptoms. Pre-exercise infrared laser therapy at 810 nm was associated with reduced

subjective soreness and improved recovery kinetics in skeletal muscle after exercise-induced damage, indicating that preventive PBM application may mitigate the onset or severity of DOMS (Vanin et al., 2016).

A recent meta-analysis by Li et al. (2024) synthesized randomized controlled trials assessing pre-exercise PBM and found that PBM can improve muscle endurance and enhance recovery from strength loss and injury, supporting its potential role in reducing DOMS and accelerating functional restoration across different activity levels.

A comprehensive meta-analysis by Luo et al. (2021) found that PBM interventions were associated with reduced muscle soreness and improved markers of skeletal muscle recovery at 24–96 h and beyond in athletic populations, supporting the therapeutic potential of light therapy when appropriately applied.

Despite these positive trends, not all studies have observed significant benefits of PBM on muscle soreness. In a randomized controlled trial, Ma et al. (2022) found that PBM alone or in combination with low-intensity stretching did not significantly reduce DOMS or improve functional outcomes in untrained individuals. Another investigation by Tsuk et al. (2020) reported no meaningful change in self-reported soreness scores following PBM compared to placebo, suggesting that treatment effectiveness may be influenced by factors such as exercise modality, energy dosage, timing of application, and the training status of participants. Similarly, a randomized crossover study by Azuma et al. (2021) reported that acute PBM at 808 nm did not significantly affect biceps brachii performance to exhaustion, perceived exertion, or delayed onset muscle soreness in untrained young adult women. This indicates that the effectiveness of PBM may be limited under certain wavelengths, dosing protocols, or in populations with low training status. Overall, the available evidence suggests that PBM can contribute to reductions in post-exercise soreness, but the magnitude and consistency of this effect vary across studies and protocols.

3.2 Effects on Muscle Recovery and Functional Performance

Beyond subjective soreness, PBM has been evaluated for its impact on objective performance measures related to muscle recovery. Multiple studies indicate that PBM can facilitate the restoration of muscle strength and functional capacity after exercise-induced damage. For instance, Leal-Junior et al. (2010) and Ferraresi et al. (2016) reported accelerated recovery of

maximal voluntary contraction and force output in PBM-treated groups relative to controls, suggesting enhanced repair processes. Similarly, Padoin et al. (2022) observed that PBM following plyometric exercise was associated with improvements in functional performance measures such as jump height, alongside attenuated creatine kinase responses, without negatively affecting adaptive responses to subsequent training sessions. These results align with the hypothesis that enhanced mitochondrial activity and improved cellular metabolism contribute to faster restoration of muscle performance after strenuous efforts. Consistent with individual RCT findings, Li et al.'s meta-analysis (2024) reported that pre-exercise photobiomodulation has beneficial effects on muscle endurance and recovery performance outcomes, lending broader evidence that PBM may offer ergogenic and restorative benefits in exercise settings.

Upadhyay et al. (2025) further support this perspective by demonstrating that PBM enhances mitochondrial efficiency in skeletal muscle, which may underpin improved recovery kinetics for strength and endurance measures following exercise-induced stress. Such mitochondrial adaptations may facilitate more efficient energy production, reduced oxidative damage, and improved metabolic resilience, all of which are key factors for functional recovery. These findings are further supported by narrative evidence indicating that PBM may enhance muscle performance, accelerate recovery of maximal voluntary contraction, and reduce biochemical markers such as creatine kinase following eccentric exercise, highlighting its potential as a multi-modal recovery strategy (Tsou et al., 2025).

Although the overall trend in the literature suggests a beneficial effect of PBM on performance recovery, some investigations have reported minimal or no significant improvements. A randomized, double-blind crossover study examining the effects of low-level laser irradiation prior to neuromuscular electrical stimulation found a protective effect on enzymatic antioxidant systems and inflammation, but no significant changes in muscle damage markers or recovery of muscle function, underscoring that PBM effects may vary depending on the exercise modality or stimulation technique. (Jówko et al., 2019). Furthermore, randomized clinical evidence suggests that the time-response window of PBM application before exercise may influence muscular outcomes, with treatments applied within several hours of exercise showing improved MVC and CK profiles compared with placebo conditions, emphasizing the importance of optimizing timing in PBM protocols (Leal-Junior et al., 2020). Variability in outcomes may reflect differences in study design, treatment parameters (e.g., wavelength,

energy density, timing), and participant characteristics, underscoring the need for carefully standardized protocols in future research.

3.3 Biochemical Markers of Muscle Damage

Exercise-induced muscle damage is commonly associated with increased levels of biochemical markers such as creatine kinase (CK), lactate dehydrogenase, and indicators of oxidative stress. Photobiomodulation (PBM) has been proposed to attenuate these responses by supporting cellular repair processes and reducing secondary muscle damage.

Several studies have reported lower CK levels following PBM application, suggesting a protective effect on muscle tissue. For example, Leal Junior et al. (2010) observed attenuated CK responses in PBM-treated participants compared to control groups, which may reflect reduced muscle membrane disruption and more efficient recovery. Similarly, Ferraresi et al. (2016) demonstrated a reduction in oxidative stress markers, indicating that PBM may help limit biochemical disturbances following exercise.

Meta-analytic evidence also indicates that PBM may attenuate biochemical markers of muscle damage such as CK, interleukin-6, and thiobarbituric acid reactive substances, indicating a modulatory effect on post-exercise inflammatory and oxidative responses in athletes (Luo et al., 2022).

However, these findings are not consistent across all studies. Tsuk et al. (2020) did not observe significant differences in CK or other biochemical markers between PBM and placebo conditions, suggesting variability in outcomes depending on study design and treatment parameters.

In addition, Antonialli et al. (2014) showed that combined laser and LED therapy influenced both muscle soreness and inflammatory biomarkers, indicating that PBM may affect multiple aspects of the muscle damage response. These effects are thought to be associated with improved mitochondrial function and increased ATP availability, which support tissue repair and cellular recovery processes (Upadhyay et al., 2025).

3.4 Effects on Inflammation and Oxidative Stress

Beyond its effects on biochemical markers, photobiomodulation (PBM) appears to influence key processes involved in exercise-induced muscle damage, including oxidative stress and inflammation. Intense physical activity increases the production of reactive oxygen species (ROS) and activates inflammatory pathways, which contribute to secondary tissue damage and delayed recovery (Powers et al., 2016).

PBM may modulate these responses through its action on mitochondrial function. By interacting with cytochrome c oxidase, PBM enhances mitochondrial respiration and supports cellular energy production, which helps regulate redox balance and reduce oxidative stress (de Freitas & Hamblin, 2016).

Evidence suggests that PBM can strengthen antioxidant defenses and limit oxidative damage following exercise. For example, Ferraresi et al. (2016) reported decreased oxidative stress markers after PBM application, supporting its role in maintaining cellular homeostasis. In line with this, Leal-Junior et al. (2015) indicated that PBM may contribute to improved recovery by reducing oxidative disturbances associated with muscle damage.

PBM also appears to modulate inflammatory signaling. It has been shown to reduce the activity of pro-inflammatory cytokines while promoting anti-inflammatory responses, which may facilitate tissue repair and recovery (Alves et al., 2020; Hamblin, 2017).

Overall, these findings suggest that PBM supports recovery through complementary mechanisms involving oxidative stress regulation and inflammation control. However, the magnitude of these effects depends on treatment parameters such as wavelength, energy dose, and timing of application (De Marchi et al., 2017; Antonialli et al., 2014).

3.5 Effects of PBM on Microcirculation and Tissue Oxygenation

Exercise-induced muscle damage and fatigue are not only associated with cellular disruption but also with transient impairments in microcirculation and oxygen delivery within skeletal muscle, which are critical for nutrient delivery and removal of metabolic by-products (Powers et al., 2016). Efficient blood flow and tissue perfusion are therefore essential for optimal recovery.

Photobiomodulation has been shown to enhance local microcirculation, potentially through its effects on nitric oxide (NO) release and vasodilation. Nitric oxide is a key signaling molecule that promotes smooth muscle relaxation in blood vessel walls, increasing blood flow to affected tissues (Hamblin, 2017; de Freitas & Hamblin, 2016). PBM-induced NO release can improve oxygen delivery and support metabolic processes necessary for recovery, contributing to reductions in muscle fatigue and faster restoration of function (Leal-Junior et al., 2015; Ferraresi et al., 2016).

Hamblin (2017) described the role of NO in PBM, noting that light absorption by chromophores can displace NO from mitochondrial binding sites, increasing its bioavailability and enhancing vasodilation. This mechanism can improve oxygen delivery to muscle fibers, potentially accelerating recovery processes.

Although direct evaluations of microcirculatory changes in human PBM studies are limited, changes in blood flow and metabolic markers reported in clinical trials indirectly support improved tissue perfusion following PBM. For example, improved functional recovery and reductions in oxidative stress markers observed in multiple studies (Ferraresi et al., 2016) may reflect secondary benefits of enhanced circulation and oxygen availability in exercised muscles.

These findings suggest that PBM's effects extend beyond mitochondrial modulation and oxidative stress regulation to include improvements in tissue perfusion, which may further facilitate muscle repair and performance restoration. However, the specific contribution of microcirculatory changes to overall recovery outcomes requires further direct investigation in well-controlled human trials.

Table 1. Summary of studies on photobiomodulation (PBM) effects on DOMS and muscle recovery

Author Year	Population	PBM Type / Wavelength	Timing of Application	Effect on DOMS	Effect on Muscle Function / Performance	Effect on Biochemical Markers / Inflammation	Notes
Leal-Junior et al., 2010	Trained men	Low-level laser, 810 nm	Post-exercise	↓ DOMS	↑ MVC	↓ CK	RCT

Ferraresi et al., 2016	Trained athletes	LED + laser, 850 nm	Post-exercise	↓ DOMS	↑ MVC, ↑ strength	↓ CK, ↓ oxidative stress	Synergistic light sources
Tsou et al., 2025	Meta-analysis	Various	Pre-/post-exercise	↓ DOMS (moderate)	↑ strength	–	Systematic review + meta-analysis
De Marchi et al., 2017	Trained men	Pulsed laser + LED	Post-exercise	↓ DOMS (best with pulsed)	↑ MVC	↓ CK	Comparison of different devices
Antoniali et al., 2014	Trained athletes	Laser + LED, 808–850 nm	Post-exercise	↓ DOMS	–	↓ IL-6, ↓ oxidative stress	Combination laser + LED enhances effect
Vanin et al., 2016	Trained men	Infrared laser, 810 nm	Pre-exercise	↓ DOMS	↑ MVC	–	Preventive PBM application
Li et al., 2024	Meta-analysis	Various	Pre-exercise	↓ DOMS	↑ muscle endurance	–	Improved strength and recovery
Luo et al., 2021	Meta-analysis	Various	Pre-/post-exercise	↓ DOMS	↑ muscle function	–	Effects observed at 24–96 h
Ma et al., 2022	Untrained adults	Laser, 810 nm	Post-exercise	No effect	No effect	–	RCT, low training status
Tsuk et al., 2020	Young women	Laser, 808 nm	Post-exercise	No effect	No effect	No change in CK	RCT, amateur participants
Azuma et al., 2021	Young women	Laser, 808 nm	Post-exercise	No effect	No effect	–	Crossover RCT
Padoin et al., 2022	Trained men	Laser, 810 nm	Post-exercise	↓ DOMS	↑ jump height, ↑ strength	↓ CK	Plyometric exercise
Jówko et al., 2019	Trained men	Laser, 810 nm	Pre-exercise + EMS	–	No change	Antioxidant modulation	Effect depends on exercise type
Zagatto et al., 2020	Elite water polo players	Full-body PBM	Post-exercise	No effect	No effect	No effect	High-intensity, whole-body protocol
Leal-Junior	Trained athletes	Laser / LED	Post-exercise	↓ DOMS	↑ MVC	↓ CK,	Focus on NO and

et al., 2015						↓oxidative stress	microcirculation
Fisher et al., 2018	Athletes	Laser / LED	Post-exercise	–	↑ muscle function	↓ CK, ↓ lactate	Compared to cryotherapy

Legend:

- ↓ – reduction / improvement
- ↑ – increase / improvement
- – – not reported or no significant effect

3.6 Summary

In summary, the collective evidence suggests that photobiomodulation may reduce delayed onset muscle soreness, enhance recovery of muscle function, and attenuate exercise-induced increases in biochemical markers of muscle damage. Mechanistic data indicate that these effects are likely mediated through enhanced mitochondrial activity, increased ATP production, and modulation of oxidative stress and inflammation. However, variability across studies, small sample sizes, and heterogeneity in treatment parameters limit definitive conclusions. Despite these limitations, PBM remains a promising supportive intervention for athletes and physically active individuals when appropriately applied, particularly in contexts where rapid recovery is a priority. Future research should focus on standardizing PBM protocols, optimizing treatment parameters, and conducting larger, well-controlled randomized trials to confirm efficacy across diverse populations and exercise modalities.

4. Discussion

The present review aimed to evaluate the effects of photobiomodulation (PBM) on exercise-induced muscle damage and recovery. Overall, the available evidence indicates that PBM may serve as a promising supportive strategy for enhancing post-exercise recovery; however, results across studies remain heterogeneous.

One of the most consistently reported findings is PBM’s potential to alleviate delayed onset muscle soreness (DOMS). Several studies demonstrated lower perceived muscle pain in participants receiving PBM compared to control or placebo conditions (Leal-Junior et al., 2010; Ferraresi et al., 2016; Tsou et al., 2025). These analgesic effects may be attributed to PBM’s

capacity to modulate inflammatory responses, enhance mitochondrial function, and reduce nociceptive signaling. Nevertheless, some randomized controlled trials reported minimal or no difference between PBM and placebo groups (Ma et al., 2022; Tsuk et al., 2020; Azuma et al., 2021), highlighting that the effectiveness of PBM likely depends on treatment parameters such as wavelength, energy density, pulsing, timing of application, and exercise modality. Participant characteristics, including training status and fitness level, also appear to modulate the response to PBM (Vanin et al., 2016).

In addition to its effects on muscle soreness, PBM appears to positively influence functional recovery and muscle performance. Improvements in maximal voluntary contraction, jump height, and force output have been reported in several studies (Leal-Junior et al., 2010; Ferraresi et al., 2016; Padoin et al., 2022). These findings are consistent with the hypothesis that PBM enhances cellular energy metabolism and accelerates repair processes via increased ATP production, reduced oxidative stress, and improved mitochondrial efficiency (Upadhyay et al., 2025). Furthermore, narrative and meta-analytic evidence supports PBM's role in improving strength recovery and attenuating biochemical markers such as creatine kinase, emphasizing its potential as a multi-modal recovery strategy (Tsou et al., 2025; Luo et al., 2021).

PBM has also demonstrated potential in attenuating biochemical markers of muscle damage. Several investigations reported reductions in creatine kinase (CK) and other indicators of muscle injury (Leal-Junior et al., 2010), while decreases in inflammatory markers and oxidative stress have also been observed (Ferraresi et al., 2016; Antonialli et al., 2014). These findings suggest that PBM may engage multiple physiological pathways critical for muscle repair, including redox homeostasis, inflammation modulation, and energy metabolism. Comparative analyses indicate that PBM may be more effective than traditional cryotherapy in improving post-exercise recovery and reducing biochemical markers such as CK and blood lactate (Fisher et al., 2018).

Despite these promising results, considerable variability exists across studies. This heterogeneity may stem from differences in PBM protocols (wavelength selection, energy dosage, pulsing, and timing relative to exercise), participant demographics, and exercise modalities. For instance, in competitive water polo athletes, Zagatto et al. (2020) reported that full-body PBM protocols did not significantly alter muscle damage markers, hormonal responses, or performance outcomes compared to placebo. Similarly, Jówko et al. (2019) demonstrated that low-level laser irradiation prior to electrically induced muscle contractions

preserved antioxidant defenses and reduced inflammation, but did not significantly alter muscle damage markers or functional recovery. These findings highlight that PBM outcomes are highly dependent on exercise modality, stimulation type, and study conditions.

From a practical perspective, PBM's non-invasive nature and low risk profile make it an attractive adjunctive tool in sports and rehabilitation contexts. In addition, standardized protocols are needed to optimize dose-response relationships, timing strategies, and participant-specific parameters. Understanding these factors is essential to translating PBM from experimental settings into routine clinical and athletic practice. Overall, while PBM shows considerable potential as a supportive recovery modality, further high-quality, well-controlled studies are necessary to establish its clinical relevance across different populations and training conditions.

5. Conclusion

Photobiomodulation (PBM) appears to be a promising strategy for supporting recovery following exercise-induced muscle damage. Evidence indicates that PBM may reduce delayed onset muscle soreness, accelerate restoration of muscle function, and attenuate biochemical markers of muscle injury, including creatine kinase and inflammatory mediators. These beneficial effects are likely mediated through enhanced mitochondrial activity, increased ATP production, improved redox balance, and modulation of oxidative stress and inflammation.

However, study outcomes remain inconsistent, largely due to variability in PBM parameters (wavelength, energy density, pulsing), timing of application, participant characteristics, and exercise modalities. While PBM shows clear potential as a supportive intervention in sports and rehabilitation settings, further high-quality, well-controlled studies are necessary to determine optimal treatment protocols, clarify dose-response relationships, and evaluate its efficacy across different populations and types of exercise. Standardization of PBM application and long-term follow-up studies will be critical for translating these findings into practical recommendations for athletes and physically active individuals. Future research should prioritize standardized PBM protocols, optimization of treatment parameters, and larger randomized controlled trials to strengthen the evidence base and guide clinical application.

Disclosure

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The authors deny any conflict of interest.

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In preparing this work, the author(s) used ChatGPT for language improvement and grammatical correction. After using this tool/service, the author(s) have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

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