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Dual therapeutic role of dienogest and vitamin E in endometriosis management and cardiovascular risk modulation; a narrative review study

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Abstract

Endometriosis is a long-lasting inflammatory condition that depends on estrogen and affects up to 10% of women of reproductive age. It is closely linked to pelvic pain, infertility, and higher heart disease risk, mainly because of increased oxidative stress and widespread inflammation. Standard treatments often help with symptoms but usually don't tackle the root causes or long-term health issues. Dienogest, a newer progestin, is well tolerated and effective at reducing pain, shrinking lesions, and preventing recurrence. Alongside this, vitamin E, a fat-soluble antioxidant, offers anti-inflammatory, anti-angiogenic, and heart-protective benefits by targeting oxidative stress, NF-κB signaling pathways, and vascular health issues. Evidence suggests that using both together might give a stronger effect: dienogest helps regulate hormones and immune responses, while vitamin E reduces oxidative damage and supports vascular health. This review indicated that combining dienogest and vitamin E could be a useful approach in treating endometriosis and lowering the risk of cardiovascular problems, emphasizing the importance of strategies that target both reproductive and overall health outcomes.

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Introduction

Endometriosis is a persistent, estrogen-driven inflammatory disorder defined by the ectopic growth of endometrial-like tissue outside the uterine cavity (1). It affects approximately 5–10% of women of reproductive age and is a major cause of pelvic pain, dysmenorrhea, and infertility. The ectopic growth of endometrial tissue triggers persistent inflammation, fibrosis, and lesion formation, leading to significant long-term health consequences and reduced quality of life (2). For a long time, people suffering from endometriosis knew about the common symptoms like severe period cramps, ongoing pelvic discomfort, and pain during sex, and struggles with getting pregnant. But over time, many also realized that endometriosis might be beyond a local issue; it's possibly a condition that affects the entire body, making it a widespread disease (3). Growing evidence from recent studies and meta-analyses indicates that endometriosis is associated with increased risks of cardiovascular conditions such as coronary artery disease and hypertension, likely driven by chronic inflammation, oxidative stress, and underlying hormonal dysregulation (4,5). A meta-analysis indicates that women with endometriosis may have up to a 60% higher likelihood of developing cardiovascular complications compared with those without the condition, underscoring the need for broader, more integrative treatment strategies to better protect long-term health (4).

Fourth-generation progestin, dienogest, has played a key role in improving the way we treat endometriosis. This medication helps break down abnormal tissue, reduces pain, and shrinks lesions by promoting a process called decidualization. Furthermore, it lowers inflammation without causing unwanted side effects like those associated with androgens or steroids (6,7). Vitamin E not only alleviates symptoms but also significantly reduces postoperative recurrence rates, and in many cases demonstrates superior effectiveness and tolerability compared with other hormonal therapies (8,9). Moreover, free radicals and oxidative stress promote the survival of endometriotic cells by sustaining vascular injury and dysfunction, highlighting the

Key point

Finding highlights that managing endometriosis requires a therapeutic perspective that also accounts for long-term systemic health, particularly cardiovascular risk. The combined use of dienogest and vitamin E represents a biologically plausible and clinically meaningful approach, as their complementary mechanisms address both the hormonal–immune dysregulation underlying endometriosis and the oxidative–inflammatory pathways implicated in cardiovascular disease. By simultaneously reducing lesion activity, alleviating pain, and improving vascular and metabolic profiles, this dual strategy may offer broader protective benefits than symptom-focused treatments alone.

supportive role of vitamin E in counteracting these pathogenic processes (10).

Vitamin E, a fat-soluble antioxidant, helps protect your body by removing harmful molecules involved in damaging fats, neutralizing reactive oxygen species, and calming down inflammation pathways. This means it can reduce the impact of both endometriosis and heart issues, making these common health problems less of a concern (10). It plays a special role in supporting our heart health and helping prevent conditions like atherosclerosis. At the same time, it's actually at the core of issues related to the overgrowth of the endometrial lining (11). Taking vitamin E and dienogest together makes a lot of sense because their combination could both help manage symptoms and target the underlying cause of the condition. The antioxidant properties of vitamin E, combined with the hormonal effects of dienogest, might work together to provide more effective relief and address the root issues at the same time.

Search Strategy

A comprehensive search strategy was developed using PubMed/MEDLINE, Scopus, Web of Science, Embase, and Google Scholar, covering all publications from database inception to March 2026. The search combined MeSH terms and free-text keywords related to endometriosis, hormonal therapy, and cardiovascular health, using Boolean operators to structure the query. Core terms included 'endometriosis', 'dienogest', 'progestins', 'vitamin E', 'anti-inflammatory agents', 'cardiovascular risk', 'oxidative stress', 'inflammation', 'hormone therapy', and 'women's health'. These were grouped into thematic blocks and combined with AND/OR to maximize sensitivity and specificity. Additional manual searching included backward and forward citation tracking and screening of relevant gynecology, endocrinology, and cardiovascular journals. Only English-language human studies addressing hormonal or antioxidant therapy, inflammation, oxidative stress, or cardiovascular outcomes in the context of endometriosis were included, while non-English papers, case reports, and studies without relevant mechanistic or clinical data were excluded.

Pathophysiology of endometriosis

Endometriosis is a chronic gynecological disorder in which endometrial-like tissue is implanted outside the uterine cavity, particularly on the peritoneal lining, pelvic structure, and ovaries (12). Approximately 10 percent of women of reproductive age are diagnosed with endometriosis, presenting symptoms like chronic pelvic pain, dysmenorrhea, and infertility (13). Its etiology is multifactorial and not completely understood; however, evidence underscores the pivotal role of oxidative stress and inflammation in lesion establishment, persistence, and progression (14).

Oxidative Stress in Endometriosis

Oxidative levels increase when the body's scavenging ability decreases, either due to excessive oxidative stress or lower levels of antioxidants (15). In retrograde menstrual blood, iron released from hemolyzed erythrocytes creates pro-oxidant factors via Fenton chemistry, leading to the formation of hydroxyl radicals and damage to cellular macromolecules (16). These oxidative insults promote lipid peroxidation, protein oxidation, and DNA damage, generating pro-inflammatory mediators that facilitate ectopic lesion survival and invasiveness (17). Furthermore, numerous studies have demonstrated that affected women show a significant decline in antioxidant activity levels, such as superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), and non-enzymatic antioxidants like vitamins C and E, which correlates with disease severity (17). Ferroptosis is a regulated, iron-dependent form of cell death driven by uncontrolled lipid peroxidation, particularly fatty acids in cell membranes (18). A recent study demonstrates that endometriotic stromal cells undergo ferroptosis; these cells secrete angiogenic and inflammatory cytokines, vascular endothelial growth factor A (VEGFA), and interleukin 8 (IL-8), promoting angiogenesis in lesions. Interestingly, in the same study, ferrotopic endometrial stromal cells treated with an antioxidant N acetylcysteine (NAC) reversed ferroptosis-induced cytokine secretion in vitro (19). In another study, it has been demonstrated that treatment with genistein as an antioxidant significantly increases SOD and GPx levels in the peritoneal fluid of endometriosis-induced mice (20).

Action mechanism of dienogest

Pharmacological profile

Dienogest is an oral progestin with a 9–10-hour half-life and over 90% bioavailability, giving it strong progestogenic activity that effectively reduces endometrial lesions. It moderately suppresses gonadotropins and has anti-androgenic and anti-proliferative effects, while remaining well tolerated for long-term use. The 2 mg daily dose is a fourth-generation progestin originally approved for treating endometriosis (21,22). Lower-dose dienogest (0.5 mg) has been shown to work as effectively as the 1-mg

dose for managing endometriosis. Since it is a progestin associated with a reduced risk of thromboembolic events, it is considered a safer option for patients over 40 years of age (23,24). Additionally, dienogest is a 19-nortestosterone–derived progestin, distinguished from similar agents by having a cyano-methyl group instead of an ethynyl group at the 17α position. Its pharmacologic action is largely localized to endometriotic tissue, with very limited angiogenic, estrogenic, glucocorticoid, or mineralocorticoid activity (24,25).

Hormonal modulation

Dienogest moderately suppresses gonadotropin secretion, leading to a reduction in the endogenous production of estradiol (25). Dienogest inhibits ovulation and, in many cases, hypomenorrhea or amenorrhea. The longer the period between the last gonadotropin-releasing hormone (GnRH) agonist injection and the first dienogest dose, the greater the number of ovulation and menstruation cycles becomes. Patients using dienogest within nine months after the last GnRH agonist had a lower reoperation rate than patients using DNG after nine months (26). Dienogest reduces estrogen levels, thereby alleviating symptoms of endometriosis independent of its antiestrogenic effect (23). and it has no glucocorticoid and no anti-mineralocorticoid activity. It also has no antiestrogenic activity, which suggests that it should not antagonize the beneficial effects of estradiol (24,27). Dienogest also reduces endometriotic lesions by creating a local progestogenic environment, while only moderately suppressing systemic estrogen levels (27). When taken consistently, dienogest binds to the progesterone receptor and inhibits systemic gonadotropin secretion (21).

Molecular and cellular effects

Dienogest exerts its therapeutic effect by inducing decidualization and subsequent atrophy of ectopic endometrial tissue while suppressing cellular proliferation through downregulation of matrix metalloproteinases and aromatase, thereby diminishing the lesion's estrogen-dependent biological activity (25). Dienogest demonstrates marked local antiproliferative activity on endometriotic lesions by reducing cell viability and suppressing proliferation in the presence of estrogen and pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α), interleukin-1β, and interleukin-32, and by downregulating proliferating cell nuclear antigen (PCNA), whose expression is significantly diminished in both glandular components and whole lesions of dienogest-treated mice compared with controls (21,28).

Anti-inflammatory and anti-angiogenic actions

Dienogest exhibits well-documented anti-inflammatory and anti-angiogenic properties (23,25), as demonstrated in both in vivo and in vitro models using eutopic and ectopic endometrial cells, where it consistently attenuates inflammatory signaling and suppresses neovascularization, mechanisms that are directly relevant to the regression of endometriotic lesions (25). Dienogest's antiproliferative and antiangiogenic actions distinguish it from other progestins (21).

Impact on endometriosis lesions

Dienogest produces a marked reduction in endometrial lesion burden (22), with experimental data showing that the volume of implanted endometrial tissue in DNG-treated mice decreases from an average of 53.70 mm^3 to 21.46 mm^3, corresponding to a 61.42% reduction compared with controls, thereby demonstrating its robust inhibitory effect on lesion growth (28). Long-term therapy with Dienogest has proven effective in controlling disease symptoms and reducing endometrioma size, with greater benefits associated with longer duration of intake and the absence of serious adverse events (29). Clinical evidence shows that daily administration of 2 mg dienogest produces a significant reduction in endometriosis-associated pain within the first 12 weeks of therapy, and continued treatment for up to 52 weeks yields a sustained and progressive decline in pain severity, underscoring its durable clinical effectiveness (30); this long-term symptom control is attributed to dienogest's strong endometrial activity, which enables its use as a monotherapy by exerting antiproliferative and anti-inflammatory effects that directly target and suppress the biological activity of endometriosis lesions (24).

Clinical use of dienogest

Effectiveness in symptom relief

Nonsteroidal anti-inflammatory drugs (NSAIDs), oral contraceptives, and progestins are widely regarded as first-line therapies for endometriosis-associated pain, and in this context, our findings indicate that dienogest may serve as an effective treatment option for women in real-world clinical practice, particularly with respect to improving health-related quality of life (HRQoL) (22). Clinical studies conducted in Europe have demonstrated that dienogest, administered at a daily dose of 2 mg, provides significantly greater pain relief in patients with endometriosis than placebo and achieves efficacy comparable to gonadotropin-releasing hormone agonists, while producing fewer hypoestrogenic adverse effects; moreover, dienogest 2 mg is characterized by a favorable safety profile, marked by only mild hypoestrogenic effects, minimal impact on bone mineral density in adult women, and low rates of treatment discontinuation (29). Dienogest significantly reduced the recurrence rate (RR = 0.37, 95% CI [0.15–0.91]; $P = 0.03$) and the incidence of hot flushes (RR = 0.24, 95% CI [0.10–0.59]; $P= 0.002$), while also providing protection against bone mineral density loss. Taken together, these findings indicate that dienogest is as effective as gonadotropin-releasing hormone analogues for the clinical management of endometriosis,

as no statistically significant differences were observed between treatment groups in the control of pelvic pain, dysmenorrhea, or dyspareunia (31).

Impact on lesion size and disease progression

The effects of dienogest on reducing the recurrence of endometrioma cysts have been extensively evaluated in comparison with treatments such as GnRH agonists and combined oral contraceptives, and its selective progestin activity is mediated through anti-inflammatory, anti-estrogenic, and pro-apoptotic mechanisms acting on endometrial tissue (32). Dienogest can also be recommended as a maintenance treatment for patients with endometriosis to decrease the rates of disease recurrence following conservative surgery (33). Dienogest inhibits ovulation and frequently induces hypomenorrhea or amenorrhea, and because a longer interval between the final GnRH agonist injection and initiation of dienogest increases the likelihood of ovulatory and menstrual cycles, patients who began dienogest within nine months of their last GnRH agonist exhibited lower reoperation rates than those who initiated treatment later, indicating that administering dienogest before menstruation resumes is an important factor in reducing endometriosis recurrence requiring surgical intervention (26). According to comparative analyses of postoperative therapies for endometriosis, dienogest and GnRH agonists demonstrate broadly equivalent overall efficacy, although dienogest appears superior in reducing postoperative recurrence. In summary, postoperative adjuvant treatment with dienogest significantly decreases pain levels and recurrence rates while improving pregnancy outcomes in patients with endometriosis, underscoring its clinical value and potential for broader implementation in practice (34). Administration of dienogest for up to five years has demonstrated a favorable safety and tolerability profile, and current evidence supports the use of medical therapy, including dienogest 2 mg, as postoperative management to prevent endometriosis recurrence, except in patients with an immediate desire for pregnancy. Moreover, dienogest 2 mg provides an effective and well-tolerated alternative to repeated surgical intervention for the long-term management of endometriosis, offering several advantages over combined oral contraceptives in sustaining symptom control and reducing disease progression (21).

Treatment duration and long-term use

The study by Kikuno et al is one of the first trial studies to compare efficacy and safety between 1 mg/day and 2 mg/day of long-term dienogest use in patients with dysmenorrhea caused by endometriosis (23). Current guidelines and expert consensus identify progestins as the first-line medical therapy for endometriosis, reflecting their efficacy, tolerability, and suitability for long-term use. Given that endometriosis is a chronic condition characterized by persistent symptoms, including pelvic pain, and a propensity for disease progression or recurrence across the reproductive lifespan, increasing emphasis has been placed on sustained medical management. Accordingly, long-term therapeutic strategies are considered essential both for alleviating endometriosis-related symptoms and for reducing the risk of recurrence (25). Evidence on the long-term use of dienogest beyond 15 months demonstrates sustained efficacy in the management of endometriosis, with experts emphasizing that its therapeutic value should be assessed primarily through its impact on pain reduction and improvements in quality of life. Administration of dienogest for up to five years has shown a consistently favorable safety and tolerability profile, and available data indicate that observed changes in bone mineral density are minimal and should not preclude its long-term use in women requiring ongoing management of endometriosis (21). Sequential therapy, consisting of an initial course of relugolix followed by dienogest, represents a novel strategy designed to optimize symptom control and sustain long-term disease management, with current findings demonstrating that this approach provides effective relief of endometriosis-related symptoms and durable disease suppression. Dienogest maintains these therapeutic gains with minimal adverse effects, supporting its role as a well-tolerated maintenance therapy within sequential treatment regimens (35).

Anti-oxidants in endometriosis treatment

Role of oxidative stress in endometriosis

Growing evidence suggests that oxidative stress plays a key role in both the onset and progression of endometriosis. When oxidative stress increases, levels of reactive oxygen species (ROS) rise, and these inflammatory molecules can damage cells. High ROS levels promote the release of pro-inflammatory cytokines and prostaglandins from macrophages and activate C-fibers through neurogenic inflammation. Together, these processes contribute to the development of pain in individuals with endometriosis (36).

Role of antioxidants and vitamins C and E in reducing endometriosis-associated pain

Antioxidants help mitigate reactive oxygen species and may reduce endometriosis-related discomfort, with vitamins A, C, E, zinc, copper, and selenium identified for their antioxidant properties. Among these, vitamins C and E are particularly suitable for long-term daily use due to their minimal adverse effects, and their combined administration enhances antioxidant capacity through "vitamin E recycling," improving lipid oxidation resistance more effectively than either vitamin alone. Both vitamins also reduce inflammation by inhibiting proinflammatory cytokines such as TNF-α, IL-1, IL-6, and monocyte-chemotactic protein-1 (MCP-1), and contribute to regulating oxidative stress associated with disturbances in iron metabolism (36).

Efficacy of NAC in endometriosis treatment

The NAC exerts antiproliferative and antioxidant effects by promoting the proliferation-to-differentiation switch and downregulating the expression of inflammatory genes and proteins. As a precursor of glutathione, NAC provides both direct and indirect antioxidant and anti-inflammatory activity, and its strong anti-inflammatory action may also reduce Cancer Antigen 125 (Ca125) levels and improve fertility. In our study, NAC administration for three months resulted in a significant reduction in the size of ovarian endometriomas, an effect likely attributable to its potent antiproliferative properties. Additionally, serum Ca125 levels decreased significantly following treatment, probably reflecting NAC's anti-inflammatory action at the peritoneal level (36).

Molecular mechanisms of vitamin E

Antioxidant and anti-peroxidative effects

A hallmark of endometriosis is a significant imbalance in redox homeostasis, with affected women consistently exhibiting elevated levels of ROS and lipid peroxidation end-products, such as MDA, in both serum and peritoneal fluid. These reactive molecules are not passive byproducts; rather, they actively contribute to DNA damage, mitochondrial dysfunction, enhanced cellular adhesion, and ultimately the survival and proliferation of ectopic endometrial lesions (37). Vitamin E serves as a primary defense against this oxidative assault. It strategically interrupts the propagating chain reactions of lipid peroxidation by donating a hydrogen atom to peroxyl radicals, thereby converting them into stable lipid hydroperoxides. This action significantly reduces the accumulation of toxic aldehydes like MDA and 4-hydroxynonenal (4-HNE) (38,39). By halting this process, Vitamin E stabilizes plasma and organelle membranes and is particularly crucial for preserving mitochondrial integrity, the primary site of ROS generation (40).

Modulation of inflammatory pathways

The link between oxidative stress and inflammation is central to the pathophysiology of endometriosis, as ROS function as potent secondary messengers that activate the key inflammatory transcription factor Nuclear factor kappa B (NF-κB). Once activated, NF-κB translocates to the nucleus and induces the expression of multiple pro-inflammatory mediators, including TNF-α, IL-6, and the enzyme cyclooxygenase-2 (COX-2). Elevated COX-2 activity drives the production of prostaglandin E_2 (PGE_2), a major contributor to pelvic pain, hyperalgesia, and the inflammatory microenvironment that supports the persistence and growth of endometriotic lesions (41). Vitamin E exerts potent anti-inflammatory effects by directly disrupting this signaling pathway, suppressing the phosphorylation and nuclear translocation of NF-κB and thereby reducing the downstream expression of its target cytokines and COX-2 (37). This upstream inhibition is a key mechanism underlying the documented anti-inflammatory and analgesic benefits of vitamin E in both experimental models of endometriosis and clinical observations (38). By suppressing NF-κB activation, vitamin E effectively disrupts the critical crosstalk between oxidative stress and chronic inflammation that drives lesion persistence and symptom severity.

Regulation of apoptosis

Vitamin E has been shown to modulate the intrinsic apoptotic pathway by downregulating the anti-apoptotic protein Bcl-2 and upregulating the pro-apoptotic protein Bax, thereby increasing the Bax/Bcl-2 ratio. This shift promotes mitochondrial outer membrane permeabilization, enabling cytochrome c release and activation of the caspase cascade, ultimately driving programmed cell death in endometriotic cells (42). This pro-apoptotic action supports tissue homeostasis by facilitating the selective clearance of ectopic cells while minimizing collateral damage to surrounding healthy tissue due to its targeted mechanism (43).

Inhibition of angiogenesis

The survival and growth of established ectopic lesions rely heavily on the development of a new blood supply, a process driven by angiogenesis. Consistent with this, pro-angiogenic factors, most notably VEGF, are found at elevated levels in the peritoneal fluid of women with endometriosis, underscoring the central role of aberrant angiogenic signaling in sustaining lesion viability and expansion (44).

Cardiovascular implications in endometriosis

Women with laparoscopically confirmed endometriosis have been shown in a growing body of epidemiological research to face a markedly elevated long-term risk of cardiovascular diseases, including ischemic heart disease, myocardial infarction, and angiographically verified coronary atherosclerosis, underscoring endometriosis as a systemic condition with significant implications beyond reproductive health (4).

Oxidative stress and lipid peroxidation in atherogenesis

The excessive OS burden characteristic of endometriosis has far-reaching systemic effects, including the oxidation of circulating low-density lipoprotein (LDL) particles. Once oxidized, LDL becomes a highly pro-atherogenic form (ox-LDL) that is rapidly taken up by macrophages, driving their transformation into lipid-laden foam cells, the defining early feature of atherosclerotic plaque formation (45). Vitamin E, which is incorporated into LDL particles, serves as a crucial first-line antioxidant defense by interrupting lipid peroxidation chains within the LDL core. Through this chain-breaking activity, it

prevents the conversion of native LDL into its highly atherogenic oxidized form, thereby reducing macrophage uptake, limiting foam-cell formation, and ultimately slowing the early initiation and subsequent progression of atherosclerotic lesions (9,45,46).

Restoration of endothelial function and nitric oxide (NO) bioavailability

The vascular endothelium, a single-cell layer lining all blood vessels, is especially vulnerable to oxidative stress, and in women with endometriosis, it shows clear signs of dysfunction (47,48). Excess ROS diminishes both the production and the bioavailability of NO, the endothelium's principal vasodilator. Superoxide anion, in particular, reacts rapidly with NO, effectively neutralizing it and reducing its capacity to maintain vascular relaxation. The resulting deficit in NO promotes heightened vascular tone, increased vasoconstriction, and a greater susceptibility to developing hypertension (49). Vitamin E preserves vascular function by scavenging superoxide to protect NO from degradation while simultaneously enhancing endothelial NO synthase activity, a dual action that improves vascular reactivity and helps guard against early vascular aging (50).

Attenuation of vascular inflammation via NF-κB suppression

Chronic, NF-κB–driven systemic inflammation in endometriosis directly impacts the vasculature by activating NF-κB signaling within endothelial cells, which subsequently increases the expression of intercellular adhesion molecule-1 (ICAM-1) and vascular cell adhesion molecule-1 (VCAM-1) (51). These adhesion molecules function as molecular "glue," promoting the recruitment and firm attachment of monocytes and other leukocytes to the vessel wall, a pivotal early event in atherogenesis, and because vitamin E potently suppresses NF-κB nuclear translocation, it lowers the expression of these endothelial adhesion molecules, thereby reducing leukocyte, endothelial interactions and the vascular inflammation that follows (37,52).

Modulation of platelet function and hemostatic balance

Endometriosis is accompanied by a subtle but clinically meaningful shift toward hypercoagulability and heightened platelet activation, a combination that further amplifies the risk of thrombotic events, including myocardial infarction and stroke, within an already vulnerable vascular system (53). Vitamin E exerts mild antiplatelet effects by inhibiting protein kinase C, a key driver of platelet activation and aggregation, and by reducing the synthesis of thromboxane A_2, a potent pro-thrombotic and vasoconstrictive mediator (54).

Conclusion

Endometriosis and cardiovascular health are closely interconnected, requiring treatment approaches that go beyond symptomatic relief. The combined use of dienogest and vitamin E offers a promising strategy that not only reduces pain and lesion progression but may also lower long-term cardiovascular risk. This synergistic effect arises from their complementary actions: dienogest regulates hormonal imbalance and immune responses, while vitamin E counteracts oxidative stress, inhibits NF-κB signaling, and supports vascular function. In addition to pharmacological therapy, lifestyle interventions such as a Mediterranean diet and regular physical activity may further enhance cardiovascular protection. Ultimately, the synergistic combination of dienogest and vitamin E represents a mechanism-based, long-term management strategy for endometriosis, addressing both reproductive symptoms and systemic cardiovascular complications. Despite these encouraging findings, current evidence remains limited regarding optimal dosing, treatment duration, and reproductive outcomes, highlighting the need for well-designed clinical trials.

Authors' contribution

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Writing–original draft: All authors.
Writing–review and editing: All authors.

Conflicts of interest

The authors declare that they have no competing interests.

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

During the preparation of this work, the authors utilized Copilot to refine grammar points and language style in writing. Subsequently, the authors thoroughly reviewed and edited the content as necessary, assuming full responsibility for the publication's content.

Ethical issues

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