



Archives of Ecotoxicology

Journal homepage: <https://office.scicell.org/index.php/AE>



Exploring the therapeutic versatility of *Centella asiatica*: From phytochemistry to pharmacology - A review

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Article info

Received 20 January 2026
Revised 3 March 2026
Accepted 8 March 2026
Published online 31 March 2026

Mini Review

Keywords:

Antimicrobial
Anti-inflammatory
Antioxidant
Phytochemical
Herbs
Centella asiatica

Abstract

Centella asiatica is a medicinal herb with great therapeutic potential and is recognized for its use in traditional medicine systems. This review aims to give an in-depth overview of the phytochemicals and pharmacological activities of *Centella asiatica*. *Centella asiatica* is found to have anti-inflammatory, antioxidant, anti-cancer, and antimicrobial activities. The phytochemicals of *Centella asiatica* include pentacyclic triterpenoids like asiaticoside, asiatic acid, madecassoside, and madecassic acid, and flavonoids, phenolic acids, and phytosterols. These phytochemicals have been found to contribute to the pharmacological activities of *Centella asiatica*. Studies have shown that *Centella asiatica* possesses anti-inflammatory properties. *Centella asiatica* suppresses pro-inflammatory cytokines and major signaling pathways. *Centella asiatica* possesses antioxidant activities. *Centella asiatica* exhibits efficient free radical scavenging activities and increases the activities of antioxidant enzymes. *Centella asiatica* has been found to possess excellent anticancer activity through the induction of apoptosis, cell cycle arrest, and the inhibition of cancer cell proliferation, migration, and invasion. *Centella asiatica* has been found to possess broad-spectrum antimicrobial activity against a wide range of Gram-positive and Gram-negative microorganisms. However, there are certain limitations and concerns regarding the standardization of the plant, lack of clinical trials, phytochemical content, and conservation status. More research and cultivation of the plant are needed to exploit the medicinal potential of *Centella asiatica* in the development of pharmaceuticals.

1 Introduction

Herbal medicines, which have been used for ages in all religions and cultures, as mentioned in ancient texts like Ramayana, Quran, and Bible, have gained popularity in the modern world as an economical treatment method with fewer side effects compared to other allopathic drugs (Shaikh and Uzgare, 2026). *Centella asiatica* is a creeping herb of the Apiaceae family, used in traditional medicine in the tropics, and is native to the warm regions of Asia, Africa, Oceania, and Central America, containing bioactive compounds (Pandey and Kulkarni, 2022). *Centella asiatica* (L.) Urban, previously known as *Hydrocotyle asiatica* (L.), comprises about 20 different species of *Centella*, commonly known as Brahmi in Unani, Mandookaparni in Ayurvedic, Gotu kola in Western, Asiatic pennywort, Indian pennywort, thick-leaved pennywort, and tiger grass (Chandrika et al., 2015). *Centella asiatica* is an important medicinal plant in international trade, as stated by the Export-Import Bank of India. The wild plant of *Centella asiatica* is facing a drastic decline in population due to excessive harvesting, less cultivation, and inadequate conservation efforts. Therefore, it is listed as a Threatened species by the International Union for Conservation of Nature (IUCN) and is considered an endangered plant (Sigh et al., 2010). The *Centella asiatica* plant contains various bioactive

compounds, such as pentacyclic triterpenes, flavonoids, phytosterols, and phenolic acids, which play a significant role in the medicinal value of the plant (Sigh and Sigh, 2024). The leaves of the plant consist of various bioactive compounds, such as asiatic acid, asiaticoside, madecassic acid, and madecassoside, which help in wound healing, venous support, and hypertension, as well as gastrointestinal disorders (Kant et al., 2019). This plant is well studied for its wound healing, cognitive-enhancing, and various pharmacological activities, including anti-inflammatory, antioxidant, antimicrobial, and cardiovascular protective effects (Orhan, 2012).

2 Materials and Methods

2.1 Literature search strategy

This review aims to provide an overview of the recent literature on *Centella asiatica* as a natural source of antioxidants, anti-inflammatory, anti-cancer, and antimicrobial agents, with special emphasis on its phytochemical profile and therapeutic importance. The literature search for this review was done between 2008 to 2026. Relevant literature was obtained using Scopus, ResearchGate, Google Scholar, and the Directory of Open Access Journals (DOAJ). The literature search was done for peer-

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<https://doi.org/10.36547/ae.2026.8.1.35-40>

reviewed articles containing phytochemical screening, in vitro, and in vivo studies of *Centella asiatica*. Literature without enough information was avoided to ensure the literature search was rigorous and comprehensive.

2.2 Data extraction

Literature search results obtained using the search engines were filtered for relevance. Relevant literature was entered into Microsoft Excel and grouped according to their abstracts, aims, and conclusions. This helped in organizing the literature in a systematic manner to ensure only relevant literature was used for this review

3 Results

3.1 Medicinal potential of *Centella asiatica*

Medicinal potential of *Centella asiatica* are given below:

3.1.1 *Centella asiatica* as a Natural Anti-Inflammatory Agent

Inflammation is a significant factor in the pathogenesis of chronic diseases like diabetes, neurodegenerative diseases, cardiovascular diseases, respiratory diseases, renal diseases, hepatic diseases, and cancer. It is usually caused by oxidative stress and increased reactive oxygen species (ROS), which induce pro-inflammatory cytokines. However, natural products with anti-inflammatory properties hold promise as therapeutic agents (Saleh and Yusuf, 2018). *Centella asiatica* is a plant that decreases inflammation by inhibiting TNF- α , IL-6, and NO; activating anti-inflammatory pathways; and accelerating collagen synthesis and wound healing. It is effective for treating skin diseases and ulcers (Witkowska, 2024). *Centella asiatica* is a plant with potent anti-inflammatory properties. In atopic dermatitis caused by phthalic anhydride-induced atopic dermatitis in mice and LPS-stimulated macrophages, the titrated extract (TECA) showed anti-inflammatory properties by inhibiting NF- κ B activation, iNOS and COX-2 expressions, and pro-inflammatory cytokines like TNF- α , IL-1 β , IL-6, and IgE (Park et al., 2017). *Centella asiatica* (CA) also shows anti-inflammatory properties on LPS-stimulated macrophages. The 70% ethanol extract (CA-70E), which is rich in asiaticoside, inhibits the production of ROS, pro-inflammatory cytokines like TNF- α , IL-6, and MCP-1; inflammatory genes like iNOS and COX-2; and the MAPK and NF- κ B pathways through TLR4, CR3, CD14, and dectin-1 receptors (Shin et al., 2024). The extract exhibited anti-inflammatory and antioxidant activity in LPS-induced BV2 microglial cells through the reduction of NO, TNF α , and ROS production. These activities were found to be mediated through the inhibition of NF κ B nuclear translocation and inactivation of Akt and ERK1/2 signaling pathways, providing promise in the management of neuroinflammatory diseases (Mairuae et al., 2019). *Centella asiatica* was also found to have the potential in enhancing diabetic wound healing through anti-inflammatory and antioxidant activity. *Centella asiatica* decreases the production of NO, iNOS, and pro-inflammatory cytokines and activates the AKT/MAPK/NF- κ B signaling pathway. Topical application on diabetic mice accelerates wound healing, providing promise in the management of diabetic foot ulcers (Xiao et al., 2013). *Centella asiatica* extract is known to be rich in bioactive compounds such as triterpenoid saponins, flavonoids, phenolic acids, and steroids. *Centella asiatica* extract has been found to have antioxidant and anti-inflammatory effects. In an in vivo study involving 25 volunteers, cosmetic formulations containing 2.5% and 5% *Centella asiatica* extract were found to have significant effects on skin hydration and anti-inflammatory effects. Cosmetic formulations containing 5%

Centella asiatica extract were found to have the best effects on skin hydration and anti-inflammatory effects. This study confirmed the moisturizing and anti-inflammatory potential of *Centella asiatica* extract in cosmetic formulations (Ratz-Lyko et al., 2016). The study aimed to evaluate the anti-inflammatory effects of *Centella asiatica* extract (CAE) on an indomethacin-induced gastric ulcer rat model. The study found that *Centella asiatica* extract has gastroprotective and anti-inflammatory effects. *Centella asiatica* extract can be used as a potential herbal therapy for gastric ulcers. This study found that *Centella asiatica* extract has anti-inflammatory effects on gastric mucosal damage. *Centella asiatica* extract was found to have downregulated COX-2 expression compared to the ulcer control (Thirza et al., 2021). *Centella asiatica* water extract has shown promising antinociceptive and anti-inflammatory properties, which are comparable to the effects of aspirin and mefenamic acid, making it a promising natural analgesic and anti-inflammatory agent (Somchit et al., 2004). *Centella asiatica* extract was also investigated for its analgesic and anti-inflammatory properties using cats undergoing ovariohysterectomy surgery. *Centella asiatica* extract, especially at 200 mg/kg, significantly reduced the pain score of the cats, indicating the analgesic and anti-inflammatory effects of *Centella asiatica* extract, making it a promising natural analgesic and anti-inflammatory agent for the treatment of postoperative pain in domestic cats (Xiao et al., 2023). *Centella asiatica* has shown promising antioxidant and anti-inflammatory properties, enhancing skin functions and relieving psoriasis symptoms. *Centella asiatica* extracts, especially the ethyl acetate extract (CAE), have shown the ability to reduce ROS, increase GSH and SOD, suppress the expression of inflammatory cytokines such as IFN- γ , IL-6, TNF- α , and CCL20, and inhibit NF- κ B and JAK/STAT3 signaling pathways, indicating the potential of *Centella asiatica* extracts for the development of functional foods and skincare products for the prevention and treatment of psoriasis (Lin et al., 2023).

3.1.2 Natural Antioxidant Properties of *Centella asiatica*

Phytochemicals are defined as non-nutrient compounds found in plants, such as polyphenols, terpenes, and nitrogen- and sulfur-containing compounds, that affect the color, taste, and smell of food, as well as having antioxidant, anti-inflammatory, antiviral, and anticancer properties (Shaikh and Uzgare, 2025; Shaikh and Uzgare, 2024). *Centella asiatica* is a herb that contains bioactive compounds such as flavonoids and terpenoids, such as asiatic acid, asiaticoside, and madecassoside, that have strong antioxidant activity. *Centella asiatica* contains compounds such as tannins, flavonoids, terpenoids, saponins, and steroids, which display strong antioxidant activity, particularly for the extracts of cell suspensions. Ultrasonic-assisted extraction was found to maximize the yield, and density functional theory analysis was conducted to reveal the potential for medicinal and drug development (Kandasamy et al., 2023). In this study, the ethanolic extract of *Centella asiatica* collected from Guilan Province in Iran was analyzed for phenolic compounds, flavonoids, flavonols, anthocyanins, antioxidant activity, and antibacterial activity. By using HPLC-DAD, the extract was found to contain compounds such as sinapic acid, catechin, quercetin, flavonols, anthocyanins, p-coumaric acid, hesperidin, eugenol, and hesperetin. Among these compounds, hesperetin was found to be the major compound in the extract. *Centella asiatica* leaves were found to possess compounds such as alkaloids, tannins, flavonoids, terpenoids, and reducing sugars. Water and ethanol extracts were found to possess considerable amounts of phenolic compounds and flavonoids. Antioxidant activity was also found to be correlated with these compounds (IC50: 1744.77 μ g/mL ethanol extract, 2324.26 μ g/mL water extract).

This indicates that the plant could be used to produce metabolites that could be used for the treatment of diseases (Quyen *et al.*, 2020). Phytochemical screening of *Centella asiatica* leaf extracts using solvents such as water, acetone, chloroform, and methanol was performed. Carbohydrates, tannins, steroids, terpenoids, alkaloids, flavonoids, cardiac glycosides, and saponins were found in the leaf extracts. Methanol extract was found to possess the maximum amount of these compounds in *Centella asiatica* (Saranya *et al.*, 2017). Oxidative stress in dermal fibroblasts plays a role in skin aging, and phytochemicals with antioxidant activities hold great promise in anti-aging. *Centella asiatica* callus culture represents a green source of phytochemicals. The 50% ethanol extract of *Centella asiatica* callus culture showed specific antioxidant compounds and afforded protection to human dermal fibroblasts against H₂O₂-induced toxicity through the activation of antioxidant enzymes and the inhibition of MMP-9. Thus, this extract may find application in anti-skin-aging products in the field of cosmeceuticals (Buranasudja *et al.*, 2021). *Centella asiatica* (L.) extracts containing flavonoids and triterpenoids have potent antioxidant activities. However, their topical bioavailability is limited. Liposome gel formulations containing 0.3% FG1 and 0.5% FG2 of *Centella asiatica* extracts showed good antioxidant activities with IC₅₀ values of around 13.9 µg/mL and controlled release. In addition, the gel formulations showed good stability at 4 °C. This indicates the potential of *Centella asiatica* extracts for topical application (Indriaty *et al.*, 2025). *Centella asiatica* compounds were also extracted using UAE, MAE, and ultrasound pre-treatment with MAE. The latter showed the highest yield and phenolic content (1289 ± 0.57 µg GAE/mL). It also showed the highest antioxidant (DPPH IC₅₀ = 38.24 µg/mL) and acetylcholinesterase inhibitory activity (IC₅₀ = 26.7 ± 0.49 mg/mL), with HPLC identification of the main compound as Madecassoside. It was therefore the most effective extraction method (Sivaneswaran *et al.*, 2023). *Centella asiatica* L. ethanolic extract (EtCA) is also a potent antioxidant. It showed the highest antioxidant activity among herbal extracts tested using the nitric oxide and superoxide radical scavenging assays. Its terpenoids, flavonoids, and polyphenols may be responsible for the antioxidant properties of the extract, which makes it a promising candidate for the formulation of a polyherbal antioxidant (Adtani *et al.*, 2016). *Centella asiatica* was found to possess free radical scavenging activity on In vitro ABTS assays, as its hydroalcoholic extract has been found to scavenge free radicals in a concentration-dependent manner. However, the activity is found to be less potent than L-ascorbic acid. This has demonstrated the potential of *Centella asiatica* to combat oxidative stress and has encouraged further research on its potential use in pharmaceuticals, cosmetics, and food supplements (Yamini *et al.*, 2014). *Centella asiatica* aqueous extracts were obtained through infusion, decoction, and ultrasonic-assisted extraction methods. It was found to possess significant antioxidant activity. Among the methods, ultrasonic-assisted extraction was found to produce the highest extract, phenolic content, and free radical scavenging activity. This has once again proved the potential of *Centella asiatica* as a source of antioxidants and has demonstrated the efficiency of ultrasonic-assisted extraction (Wan Zainal *et al.*, 2019).

3.1.3 Pharmacological Insights into the Anticancer Activities of *Centella asiatica*

Cancer is one of the significant health issues affecting the global population, and medicinal plants have been seen as a promising option for the prevention and treatment of cancer with the help of bioactive compounds present in them that inhibit the growth of tumor cells (Rehan & Sambhaji 2025). *Centella asiatica* is a medicinal plant with bioactive compounds such as asiaticoside

and madecassoside with antioxidant, anticancer, and therapeutic properties. The anticancer effect is seen through the modulation of oxidative stress, apoptosis, and anti-angiogenesis; however, the clinical validation and processing need to be done (Sen *et al.*, 2026). *Centella asiatica* extract was tested on oral cancer cells with different concentrations and intervals of time. Cisplatin was taken as a reference substance. It was seen that the viability of the cells was inhibited significantly with a dose- and time-dependent manner ($p < 0.05$) (Vijayakumar *et al.*, 2023). *Centella asiatica*, also has bioactive compounds such as Asiatic acid and Asiaticoside that have shown anticancer activity against breast cancer cells (MCF-7) and ovarian cancer cells (SKOV-3 and OVCAR-3) in a dose-dependent manner (Shaikh *et al.*, 2024). Chloroform extract from *Centella asiatica* leaves has shown the presence of bioactive compounds such as flavonoids, alkaloids, glycosides, and amino acids. The extract has shown dose-dependent cytotoxicity in A549 human lung cancer cells using the MTT assay, proving the anticancer potential of *Centella asiatica*. Flavonoids and alkaloids have shown the ability to induce apoptosis in cancer cells and inhibit metastasis and antioxidant activity, making *Centella asiatica* a potent source for anticancer drugs (Sinduja *et al.*, 2025). *Centella asiatica* extract has shown significant anticancer activity in mice, reducing the occurrence of papilloma and melanoma tumors in mice along with reducing their sizes and weights, thus increasing their lifespan (Rai *et al.*, 2014). Triterpenoids from *Centella asiatica* asiatic acid, madecassic acid, and asiaticoside were shown to suppress the migration and invasion of A549 lung cancer cells induced by radiation at non-toxic concentrations, indicating its potential as a natural adjuvant for radiotherapy in non-small-cell lung cancer (Han *et al.*, 2020). ECa 233, a standardized *Centella asiatica* extract, suppressed the growth of oral cancer cells by inducing apoptosis and G0/G1 cell cycle arrest, and also reduced migration, invasion, and colony formation, indicating its potential as an adjuvant anticancer therapy (Manmuan *et al.*, 2024). *Centella asiatica* leaves containing asiatic acid, madecassic acid, asiaticoside, and madecassoside exhibited potential anticancer activity against benzo(a)pyrene-induced lung tumors in mice. Administration of 250-750 mg/kg of ethanolic extract suppressed tumor nodules, blocked bronchial epithelial hyperplasia, and reduced tumor foci in lungs, indicating its chemopreventive property (Hamid *et al.*, 2016). The methanolic extract of *Centella asiatica* was investigated for its apoptosis-inducing activity in cancer cells. Among the cell lines, MCF-7 was most sensitive, undergoing apoptosis characterized by nuclear condensation, enhanced annexin staining, loss of mitochondrial membrane, and DNA fragmentation (TUNEL assay). These findings indicate the potential of *C. asiatica* extract in herbal anticancer therapy (Babykutty *et al.*, 2008).

3.1.4 *Centella asiatica*: A Natural Antimicrobial Agent

Plant-derived compounds with significant antimicrobial properties are also under consideration for the treatment of bacterial, fungal, viral, and parasitic infections. Plant extracts still hold significance in the search for effective antimicrobial compounds (Shaikh and Uzgare, 2025). Ethanolic extract of *Centella asiatica* possessed the strongest antimicrobial activity among the bacteria and fungi tested with a minimum inhibitory concentration ranging from 7.81-125 mg/mL. Methanol, water, and hexane extracts were also effective. It may be a natural substitute for synthetic food preservatives (Wong and Ramli, 2021). The present study evaluated the *Centella asiatica* extracts with 25-75% ethanol content. The strongest antioxidant and antibacterial activity were observed with the 75% ethanol content extract against *E. coli*, indicating its significant therapeutic value (Latirah, and Nugroho, 2024). *Centella*

asiatica was found to possess antibacterial properties. Soxhlet extraction with ethanol, methanol, and water showed the highest yield and antibacterial activity with ethanol. The antibacterial activity was significant against *Bacillus subtilis*. This shows the antibacterial potential of *Centella asiatica* (Idris and Nadzir, 2017). *Centella asiatica* possesses broad-spectrum antibacterial activity. Hydroalcoholic leaf extracts of *Centella asiatica* were found to contain triterpenoids and flavonoids. The antibacterial activity was found to be dose-dependent on *Staphylococcus aureus*, *Bacillus subtilis*, and *Escherichia coli*. It was found to be more active on *Staphylococcus aureus* and *Bacillus subtilis* than chloramphenicol (Routh et al., 2025). Methanolic extracts of *Centella asiatica* were found to contain asiatic acid and madecassoside. It was found to possess broad-

spectrum antibacterial activity. Asiatic acid was found to be more active than madecassoside on *Escherichia coli* and *Staphylococcus aureus*. This shows the antibacterial potential of *Centella asiatica* (Bisht et al., 2024).

3.1.5 Pharmacological Activities of *Centella asiatica*

Centella asiatica has shown a range of pharmacological effects, which have been attributed to the bioactive compounds like asiaticoside, madecassoside, asiatic acid, and madecassic acid. These effects have been mediated by antioxidant, anti-inflammatory, and anticancer agents like the ones described in Table 1.

Table 1 Summary of pharmacological activities of *Centella asiatica*

Pharmacological Activity	Principal Bioactive Constituents	Molecular and Cellular Mechanisms	References
Anti-inflammatory	Triterpenoid saponins (asiaticoside, madecassoside); standardized ethanolic and aqueous extracts	Downregulation of pro-inflammatory mediators like TNF- α , IL-6, IL-1 β , NO, COX-2, and iNOS; inhibition of NF- κ B nuclear translocation; modulation of MAPK (ERK, JNK, p38) and JAK/STAT pathways; suppression of intracellular ROS formation.	(Park et al., 2017; Shin et al., 2024)
Antioxidant	Flavonoids, phenolic compounds, triterpenes (asiatic acid, madecassic acid)	Direct free radical scavenging activity (DPPH assay, ABTS assay); augmentation of endogenous antioxidant systems like superoxide dismutase and glutathione peroxidase; increase in the levels of reduced glutathione; suppression of lipid peroxidation and oxidative cellular damage.	(Shaik and Khaton, 2023; Kandasamy et al., 2023; Wan et al., 2019)
Anticancer	Asiatic acid, asiaticoside; methanolic and ethanolic extracts	Induction of intrinsic pathways of apoptosis (activation of caspase-3/9, modulation of Bax/Bcl-2); cell cycle arrest in G0/G1 or G2/M phase depending on the cell type; inhibition of angiogenesis-related signaling pathways; suppression of tumor cell migration and invasion via MMP modulation.	(Sen et al., 2026; Babykutty et al., 2008; Han et al., 2020)
Antimicrobial	Asiatic acid, madecassoside; ethanol and methanol extracts	Inhibition of bacterial growth by disrupting cell membranes and interfering with cellular metabolism; has been shown to be active against both Gram-positive and Gram-negative bacteria.	(Routh et al., 2025; Bisht et al., 2024)

4 Discussion

The combined results of the studies indicate that *Centella asiatica* holds great therapeutic potential, which can be ascribed to its complex mixture of triterpenoids, flavonoids, and phenolic compounds. The anti-inflammatory activity of *Centella asiatica* is associated with the regulation of critical signaling pathways, including NF- κ B, MAPK, and JAK/STAT, as well as the inhibition of pro-inflammatory cytokines and oxidative stress markers. The significant antioxidant activity of *Centella asiatica* further confirms its role in the prevention of chronic diseases and skin aging. In addition, the anticancer potential of *Centella asiatica*, based on preclinical studies, indicates its ability to induce apoptosis, cell cycle arrest, and inhibit the progression of various types of cancer. The wide-spectrum antimicrobial activity of *Centella asiatica* further enhances its pharmacological value, but it is of critical importance to design more standardized studies to translate its therapeutic value into medical applications.

5 Conclusion

Centella asiatica, an important medicinal plant, exhibits considerable pharmacological importance and therapeutic potential with its diverse range of bioactive compounds, which

include asiaticoside, asiatic acid, madecassoside, and flavonoids. This medicinal plant exhibits anti-inflammatory, antioxidant, antimicrobial, anti-cancer, wound healing, and neuroprotective activities through the modulation of major molecular mechanisms of inflammation, oxidative stress, antimicrobial effects, and cell repair. The pharmacological importance of this medicinal plant makes it increasingly relevant to the pharmaceutical, nutraceutical, and cosmeceutical industries. However, there are some issues with the therapeutic application of this medicinal plant. Firstly, this medicinal plant exhibits considerable variation in phytochemicals. In addition, there is a lack of standardization in the extraction of this medicinal plant. Moreover, there is a lack of information regarding the long-term safety and dosing of this medicinal plant.

Future Perspectives

The priority research directions that need to be addressed for the clinical and therapeutic development of *Centella asiatica* are as follows:

- Standardization of *Centella asiatica* extracts to establish a consistent phytochemical content and therapeutic response
- Conducting well-designed, large-scale randomized controlled trials for specific therapeutic indications.

- Elucidating the optimal dosage regimens, pharmacokinetics, and long-term safety of *Centella asiatica*.
- Developing innovative drug delivery systems to maximize bioavailability and therapeutic effectiveness.
- Evaluating the possibility of drug interactions with *Centella asiatica* to ensure safe use.
- Promoting sustainable cultivation and conservation of *Centella asiatica* to protect natural sources.
- Improving quality control and regulatory frameworks for pharmaceutical and nutraceutical use.

By addressing these research priorities, the integration of *Centella asiatica* into contemporary therapeutic practice can be facilitated, and its development as a medicinal plant can be continued.

Statements and Declaration

Acknowledgement

The authors would like to acknowledge the valuable contributions of fellow researchers, whose work is cited in the references section, for their insightful publications that have stimulated and enriched this review paper. The tables and figures are made by the authors themselves and are not copied from any sources.

Human Ethics and Consent to Participate declarations

NA

Availability of data and materials

NA

Funding

NA

Clinical Trial Number

NA

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