Research Article

Enhancing Bioactive Recovery From Amla Using Ultrasound-Assisted Extraction

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Abstract | Amla (*Emblica officinalis*) contains bioactive compounds such as flavonoids, phenolic acids, and ascorbic acid, which exhibit antioxidant, antimicrobial, and anti-inflammatory properties. This study utilized ultrasound-assisted extraction (UAE) process to enhance bioactive recovery from amla and compared its efficiency with maceration. The effects of extraction time (2–8 min) and material to solvent ratio (1:5–1:25 g/mL) on yield and bioactive content were evaluated. Amla fruit powder was extracted using ethanol as solvent. Within the examined experimental range, the optimal extraction conditions were 4 minutes and a 1:15 material to solvent ratio, yielding 31.0% extract, higher than maceration (29.0% in 72 hours). UAE also enhanced total flavonoid content (12.08 mg QE/g) and total phenolic content (236.7 mg GAE/g). Fourier Transform Infrared Spectroscopy confirmed the presence of bioactive compounds in extracted product. Scanning electron microscopy analysis showed UAE induced faster and more extensive structural damage, facilitating efficient compound extraction compared maceration. This study demonstrates that UAE is a rapid, efficient, and reducing extraction time while enhancing extraction yield. It supports eco-friendly extraction practices in nutraceutical and pharmaceutical industries.

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Keywords | Amla, Bioactive compounds, Maceration, Ultrasound-assisted extraction.

Introduction

Amla (*Emblica officinalis*), also known as Indian gooseberry, is a tropical fruit famous for its rich content of bioactive compounds such as phenolic acids, flavonoids, tannins, and vitamin C. These compounds contribute to its antioxidant, antimicrobial, and anti-inflammatory properties, making amla a valuable ingredient in traditional medicine and nutraceutical applications (Husna *et al*., 2024). Amla fruit is rich in various phytoconstituents, including vitamin C, phenolics, flavonoids, alkaloids, flavones, terpenoids, and tannins (Chahal *et al*., 2019; Tewari *et al*., 2023). Due to its rich phytochemical composition, amla is recognized for its therapeutic potential in treating skin disorders, gastric ailments, diabetes, hypertension,

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and cardiovascular diseases (Chaikul *et al*., 2021; Tewari *et al*., 2024). Given its pharmacological significance, efficient extraction methods are essential to maximize the recovery of bioactive compound.

Previous studies have explored different extraction techniques to obtain bioactive compounds from amla. Maceration, soxhlet extraction, and hydrodistillation have been widely used but require prolonged extraction times and large solvent volumes, limiting their efficiency. Alternative approaches, such as supercritical fluid extraction and microwave-assisted extraction, have been investigated to improve extraction efficiency, but these methods often involve high operational costs and complex setups (Patra *et al*., 2022). Ultrasound-assisted extraction (UAE) is a highly effective non-thermal technology that has recently gained significant attention in food processing due to its efficiency, simplicity, portability, and cost-effectiveness (Aslam *et al*., 2023). UAE operates using high-frequency ultrasonic waves (≥ 20 kHz) to disrupt cell walls, facilitating the release of bioactive compounds. Compared to maceration, UAE offers higher extraction yields, increased mass transfer rates, and the ability to operate at lower temperatures, thereby preserving the integrity of heat-sensitive compounds (Patra *et al*., 2022).

In recent years, several studies have explored the extraction of bioactive compounds from amla fruit. Manikandan *et al*. (2019) investigated the production of antioxidant polyphenols from *Phyllanthus emblica* using the Soxhlet extraction method. Similarly, Raaf *et al*. (2023) examined the impact of particle size on the yield, phenolic, and flavonoid content of amla extract obtained through maceration. However, research focusing on the optimization of ultrasound-assisted extraction (UAE) parameters for enhancing bioactive compound recovery remains limited. Recent studies, such as Husna *et al*. (2024), have focused on optimizing UAE conditions; however, a more comprehensive comparison with conventional extraction methods is still needed. The novelty of this study lies in its detailed investigation of the effect of extraction time and solvent ratio on bioactive compound recovery from amla using UAE, along with a comparative analysis to maceration, contributing valuable insights for optimizing UAE in sustainable extraction processes. The findings of this research contribute to advancing sustainable extraction methodologies, aligning with global efforts to reduce industrial solvent usage and energy consumption.

Materials and Methods

Materials

Amla fruit was procured from Aceh Besar District, Indonesia. The chemicals used was purchased from Merck (Indonesia), included ethanol (95% purity), Biuret reagent, petroleum ether (40-60 deg C), CH_3COOK (≥ 99% purity), $AlCl_3$ (98% purity), Folin-C ((≥ 90% purity), and Na_2CO_3 (≥ 99% purity). All chemicals were used as received, without any additional purification.

Experimental procedure

The experimental procedure is presented in Figure 1. The experiments were performed on a laboratory scale. A single-factor design was chosen to focus on the effect of individual experimental variables (material-to-solvent ratio and extraction time) on the extraction process. This design is easier to understand, implement, and analyze, as it isolates the impact of each factor. Additionally, a single-factor design requires fewer resources, making it more efficient for conducting a detailed and focused evaluation.

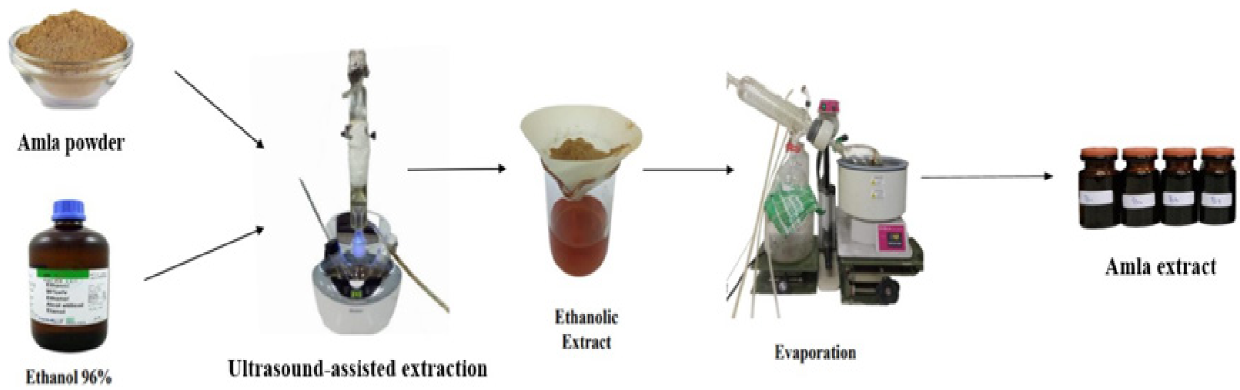

Figure 1: *Diagram depicting the sequence of UAE*

The amla fruit was thoroughly washed under running water to remove impurities. The outer skin was peeled, and the flesh was sliced thinly using a slicer. The slices were dried in an oven at 45°C for 10 hours, ground into powder using a blender, and sieved through 40- and 60-mesh sieves. The fraction retained in the 60-mesh sieve was used for extraction.

Amla fruit powder (6.5 g) was placed in a three-neck flask, and 70% ethanol was added at different material to solvent ratios (1:5, 1:10, 1:15, 1:20, and 1:25 g/mL). UAE was performed at room temperature (28°C) for 2, 4, 5, 6, and 8 minutes using an ultrasonic cleaning bath system (Krisbow, Indonesia) at 47 kHz frequency. The mixture was filtered through Whatman No. 1 filter paper, and the filtrate was concentrated with a rotary vacuum evaporator (100 mbar, 40°C, 100 rpm). The resulting thick extract was weighed, stored in dark vials for further analysis. The experiments were conducted in triplicate to ensure data reproducibility, and the average values of the measured data were reported. The experimental error across all trials was found to be less than 5%, indicating that variations in the collected data under identical conditions were insignificant (Supardan *et al.*, 2019). The extraction yield was calculated using Eq. (1).

$$\% \text{ Yield} = \frac{\text{weight of extract}}{\text{weight of raw material}} \text{ x } 100\%$$

Analysis methods

UV-vis spectrophotometer (VIS 722N) was used to determine the quantitative information regarding the content of bioactive compounds in Amla fruit extract. The quantification of bioactive compounds followed the outlined procedures by Oramahi *et al.* (2024). The utilization of a pre-prepared calibration curve facilitates the determination of bioactive components concentration. Fourier Transform Infrared spectroscopy (FTIR Shimadzu, IRPrestige 21) was used to identify the functional groups of the amla extract. The shape of the spectra presented and the positions of the absorption bands are expressed as wavenumbers and are used to identify the functional groups present in the sample. The spectrum is taken in the wavenumber region of 4000–400 cm^{-1}.

Results and Discussion

Proximate analysis of dried amla powder

Table 1 shows the proximate composition of the dried amla powder. Carbohydrates accounted for the highest proportion (81.9%), while fat content was the lowest (1.23%). These findings align with previous studies reported by Mishra and Mahanta (2014). The slight variation in fat and protein content may be attributed to differences in geographical location and environmental conditions (Okeke *et al.*, 2021). The moisture content (8.85%) was within acceptable limits to prevent microbial growth, as suggested by Zambrano *et al.* (2021).

Table 1: *Proximate analysis of amla fruit powder*

Parameter	Amount (%)
Water content	8.85
Ash content	3.07
Fat level	1.23
Protein content	4.95
Carbohydrate levels	81.90

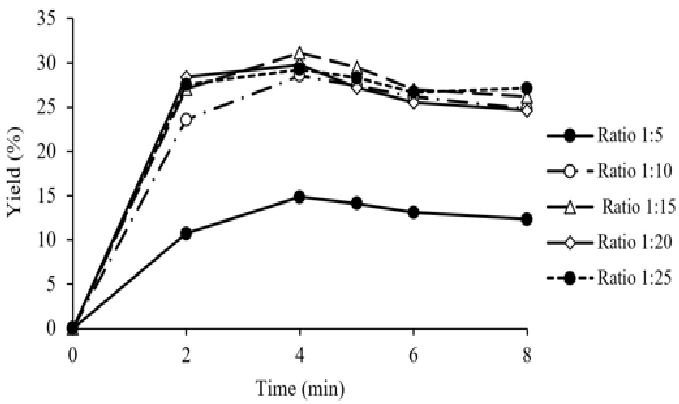

Figure 2: *Effect of extraction time and material to solvent ratio on the yield*

Effect of extraction time and material to solvent ratio on yield

The extraction yield of amla fruit was significantly influenced by both extraction time and material to solvent ratio (Figure 2). The highest yield (31.0%) was obtained at an extraction time 4 minutes and a material to solvent ratio 1:15 g/mL. Initially, increasing extraction time led to greater compound diffusion due to prolonged solvent contact, enhancing mass transfer. However, beyond 4 minutes, a decline in yield was observed, likely due to the degradation of thermosensitive bioactive compounds such as phenolics and ascorbic acid, as reported by Tewari *et al.* (2024). A comparable research outcome was reported by Li *et al.* (2023) in their study on the extraction of ursolic acid from apple peel. They observed that the extraction yield declined with longer ultrasonic time, dropping from 1.56% at 30 minutes to 1.35% at 75 minutes. Prolonged ultrasonication raised the extraction temperature, which in turn degraded ursolic acid due to extended exposure to ultrasonic radiation, ultimately reducing the yield.

The material to solvent ratio also played a crucial role in extraction efficiency. A higher material to solvent ratio facilitated greater bioactive compound diffusion, with the highest extraction yield recorded at 1:15 g/mL. Further increases in solvent volume did not significantly enhance the yield, possibly due to dilution effects reducing solvent saturation capacity. This trend supports earlier reports that achieving the proper material to solvent ratio is critical to enable effective compound diffusion and to prevent over-dilution, which may otherwise hinder mass transfer (Li *et al*., 2023). The combined effect of extraction time and material to solvent ratio highlights the importance of optimizing these parameters to maximize yield while preventing compound degradation.

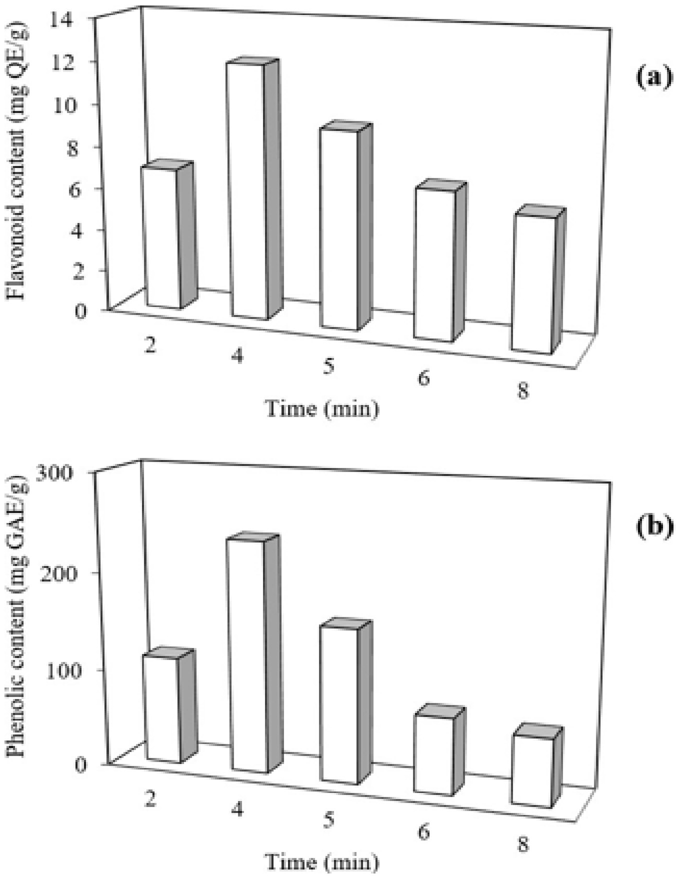

Figure 3: *Effect of extraction time on: (a) total flavonoid content; and (b) total phenolic content*

Effect of extraction time on phenolic and flavonoid content

The effect of extraction time on phenolic and flavonoid content was further investigated at material to solvent ratio 1:15. The total phenolic and flavonoid content varied with extraction time (Figure 3). The highest flavonoid content (12.08 mg QE/g) and total phenolic content (236.72 mg GAE/g) were obtained at 4 minutes. During the initial stage of extraction, sonication effectively facilitates the release of bioactive compounds from plant cells. Ultrasonic waves enhance heat and mass transfer by disrupting or breaking cell walls, thereby improving the extraction efficiency of targeted bioactive components. However, prolonged sonication may lead to the degradation of phenolic compounds, potentially reducing their overall yield (Tiwari, 2015). These results are in agreement with previous findings (Husna *et al*., 2024; Tewari *et al*., 2024), indicating that extended extraction initially enhances mass transfer but excessive sonication leads to degradation. A decrease in phenolic content at 8 minutes suggests compound breakdown due to overexposure to ultrasonic waves. Thus, optimizing extraction time is crucial to balancing yield and bioactive compound preservation

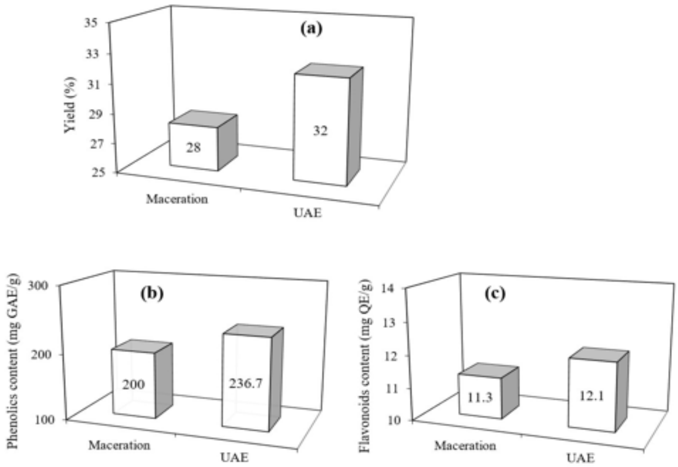

Figure 4: *Effect of extraction method on: (a) extract yield; (b) total phenolics content; and (c) total flavonoids content*

Comparison of UAE and maceration

The UAE method demonstrated superior extraction efficiency compared to maceration. Under similar extraction condition (material to solvent ratio 1:15), UAE produced a higher yield (31.0% in 4 minutes) compared to 29.0% in 72 hours for maceration (Figure 4(a)). Thus, UAE increased extraction yield by 6.9%, reducing processing time by 96% compared to maceration. In the maceration method, the transfer of extract compounds to the solvent is much less and the yield is lower. UAE has been recognized as an effective technique for extracting phytochemicals from plants (Tuan *et al*., 2025). UAE enhances solvent penetration by inducing cell disruption, facilitating faster bioactive compound release. UAE consistently outperformed maceration, confirming its superiority in bioactive extraction. Enhanced solvent penetration in ultrasonic extraction leads to the recovery of greater amounts of phenolic and flavonoid compounds, as shown in Figures 4(b) and 4(c). These findings align with Albuquerque *et al.* (2025), who compared heat-assisted extraction (HAE) and ultrasound-assisted extraction (UAE) for anthocyanin recovery from *Sicana odorifera* fruit epicarp. They reported HAE yields of 23% (w/w) extract, while UAE achieved 26% (w/w) in significantly less time (23 vs. 62 min). Likewise, Liu *et al.* (2024) showed that UAE outperformed conventional extraction methods for phenolics from grape marc, producing higher bioactive yields with reduced processing time. This study further supports UAE as a sustainable, energy- and cost-efficient method that enhances bioactive compound recovery while reducing extraction time.

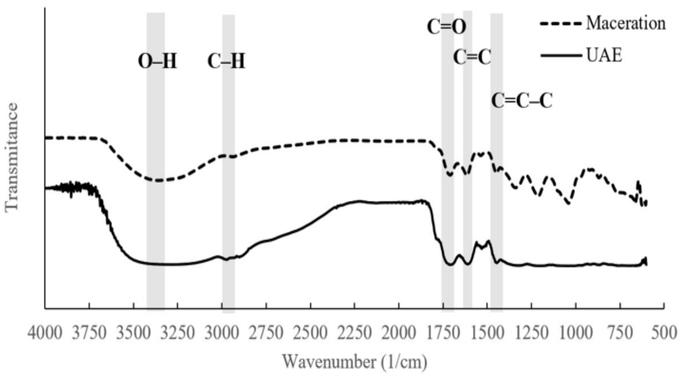

Figure 5: *FTIR spectrum of amla extract*

FTIR analysis was performed to determine the bioactive compounds in the amla extract by examining their functional groups (Figure 5). The FTIR spectra revealed several prominent peaks. The band at 3350–3370 cm^{-1} corresponds to O–H stretching (H-bonded), indicating the presence of phenols and alcohols (Nandiyanto *et al.*, 2019). The C–H vibration was observed at 2950–3000 cm^{-1}, associated with phenolic aromatic compounds. The peak at 1700–1750 cm^{-1} represents the C=O stretching of ester groups (Rosalina *et al.*, 2022). Additionally, bands at 1470–1490 cm^{-1} and 1620–1650 cm^{-1} correspond to C=C–C stretching of aromatic rings and C=C groups of phenolic aromatic compounds, respectively (Öztürk *et al.*, 2018). The presence of polyphenol compounds was confirmed by the functional groups C–O, C=O, and –OH. The ester group further indicates the presence of tannins, saponins, and flavonoids (Raaf *et al.*, 2024). Overall, the FTIR spectra aligned well with previous studies, demonstrating consistency with the findings of Firdous *et al.* (2021).

The surface morphology of amla powder is illustrated in Figure 6. SEM analysis showed structural changes in amla powder during extraction. Before extraction, intact cell walls were observed (Figure 6a). After 72 hours of maceration, initial cell wall ruptures appeared (Figure 6b), while 8 minutes of UAE caused significant cell disruption (Figure 6c), enhancing

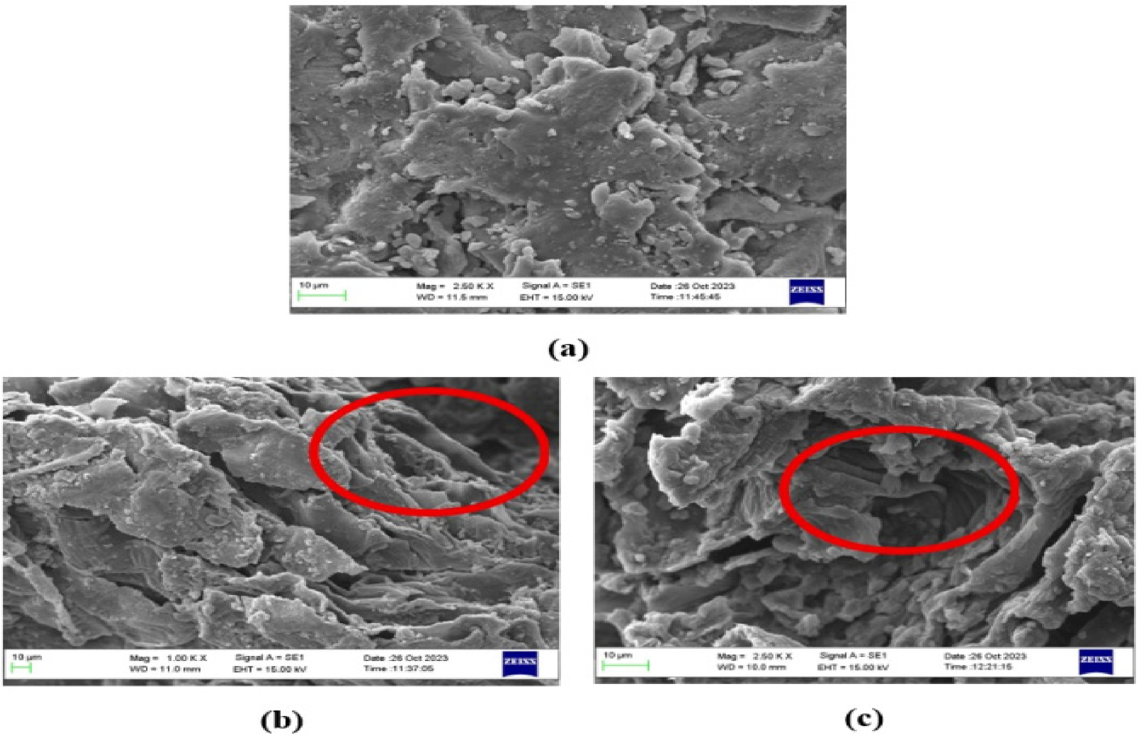

Figure 6: *Morphological structure of amla powder: (a) before extraction; (b) after 72 hours of maceration; and (c) after 8 minutes of UAE*

solvent accessibility and facilitating rapid bioactive release. This effect results from ultrasonic vibrations, cavitation waves, and the mechanical impact of ultrasonication, which lead to molecular disruption within the cell wall. Compared to maceration, UAE induced faster and more extensive structural damage, facilitating efficient compound extraction. This phenomenon aligns with the findings by Hsu and Yang (2024), who observed similar results in extraction of polyphenols, cynarin, and chlorogenic acid from *Arctium lappa* L. roots treated with ultrasound.

Conclusions and Recommendations

This study demonstrates that ultrasound-assisted extraction (UAE) is a superior method for extracting bioactive compounds from amla, outperforming maceration in yield and efficiency. Optimal UAE conditions (4 min, 1:15 g/mL) resulted in a 31.0% extract yield, higher than maceration (29.0% in 72 h), with enhanced flavonoid and phenolic content. FTIR analyses confirmed the presence of key bioactive compounds. These findings establish UAE as a rapid and efficient extraction technique, reducing processing time while preserving bioactive integrity. Its application in nutraceutical and pharmaceutical industries holds significant potential. Future research should explore industrial-scale implementation and alternative solvent systems to further optimize extraction efficiency.

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Novelty Statement

This study distinctly highlights the comparison with maceration to underscore the advantages of ultrasound-assisted extraction in improving the efficiency of bioactive compound extraction from amla (*Emblica officinalis*).

Authors' Contribution

Yanna Syamsuddin: Designed the research and wrote the manuscript.
Nabila Mulya Rahma Rizky and Dini Hayatul Nufus: Conducted the experiment.
Satriana and Auliyaa Raaf: Planned the research, wrote and edited the manuscript.
Muhammad Dani Supardan: Provided guidance throughout the research process and reviewed the manuscript.

Generative AI or AI assisted technology statement
During the preparation of this manuscript, the authors utilized ChatGPT to improve the clarity of the writing. Subsequently, the authors carefully reviewed and edited the content as necessary and take full responsibility for the final publication.

Conflict of interest
The authors have declared no conflict of interest.

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