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Evaluation of Polymethylmethacrylate with Intramedullary Titanium K-Wire Fixation for Long Bone Fractures in Birds

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ABSTRACT

This study aimed to evaluate the clinical efficacy of polymethylmethacrylate (PMMA) combined with intramedullary titanium K-wire fixation for long bone fractures in birds and compare outcomes with titanium K-wire fixation alone. A comparative study on 12 birds randomly divided into two equal groups (Group I: titanium K-wire alone; Group II: titanium K-wire with PMMA). Twelve birds (wild and domestic) with long bone fractures (humerus, radius-ulna, femur, tibiotarsus) underwent open reduction and intramedullary pinning. Clinical examination, radiographic evaluation and lameness assessment were performed. Group II demonstrated significantly ($P<0.05$) higher radiographic scores on days 7, 21 and 45 (mean day 45: 5.66±0.21 vs. 4.33±0.65), indicating accelerated healing. Lameness scores decreased significantly ($P<0.05$) in Group II on days 7, 21, 45 compared to Group I. Total leukocytes decreased significantly ($P<0.05$) from day 0 to 7 in both groups (Group I: 20.46±1.52 to 15.68±0.70; Group II: 15.60±1.80 to 12.65±0.37 $\times 10^3$/L). Heterophils decreased significantly ($P<0.05$) from day 0 to 7 (Group I: 72.33±3.64 to 62.33±2.74%; Group II: 66.83±1.07 to 58.16±0.65%). Lymphocytes increased significantly ($P<0.05$) by day 7 in both groups. Overall functional recovery was very good to good in 83.33% (5/6) Group II birds versus 66.67% (4/6) Group I birds. Study was concluded PMMA combined with titanium K-wire fixation provides superior biomechanical stability, accelerated radiographic and clinical healing, improved early limb function and reduced post-operative complications compared to K-wire fixation alone in avian long bone fractures.

HIGHLIGHTS

- Use of polymethylmethacrylate for fracture repair in birds.
- Use of titanium K-wire for fracture repair in birds.

Keywords: Avian orthopedics, polymethylmethacrylate, titanium K-wire, intramedullary pinning, long bone fractures, fracture healing

Birds constitute a diverse group of 27 orders, 168 families and approximately 10,000 species globally, all characterized by unique skeletal adaptations for flight (Ludders, 2015). The avian skeleton differs fundamentally from mammalian bone, being pneumatic with many bones connected to the respiratory system, facilitating oxygen uptake during sustained flight. This architectural adaptation renders avian bones lighter yet more brittle and fracture-prone than mammalian counterparts. Avian bones lack the Haversian system present in mammals and contain medullary cavities intersected by bony trabeculae and struts for strength. Elevated calcium content increases bone fragility despite specialized structure, predisposing

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birds to open, comminuted fractures upon impact (Tully, 2002).

Traditional fracture management employed external coaptation (bandaging and splinting), offering economy and non-invasive approach. However, external fixation provides inadequate stability, promotes excessive periosteal callus formation, causes muscle atrophy, requires prolonged immobilization (5-8 weeks) and complicates post-operative rehabilitation and wild bird release (Coles, 2007). External coaptation fails to resist rotational forces, often resulting in malunion and functional disability.

Internal fixation via intramedullary pinning provides superior biomechanical stability by resisting axial and bending forces with minimal vascular disruption and soft tissue damage (Gaebler *et al.,* 2011). Titanium alloys are preferred over stainless steel due to enhanced biocompatibility, lower elastic modulus approximating bone, superior osteointegration, reduced osteolytic potential and enhanced fatigue resistance (Venable *et al.,* 1937). However, intramedullary pins alone lack resistance to rotational forces and may migrate due to thin avian cortices and medullary cavity geometry (Tornetta and Mirick, 1995).

Polymethylmethacrylate (PMMA), an acrylic bone cement, functions as a luting agent, filling medullary cavity interstices and creating mechanical bonds that enhance rigid fixation and enable smaller-diameter pins. When combined with intramedullary pinning, PMMA prevents pin migration, enhances rotational stability and facilitates endosteal callus formation. PMMA can be mixed with antibiotics (gentamicin, ceftiofur) to provide localized antimicrobial therapy, reducing infection risk in contaminated wounds (Borman *et al.,* 1978). PMMA's exothermic polymerization reaction presents risk of thermal osteonecrosis, but careful thermal management via cold saline irrigation mitigates this risk (Bowen, 2011).

The clinical study aims to generate preliminary evidence that may guide future controlled trials and refinement of avian fracture fixation protocols. This prospective comparative study was designed to evaluate the clinical, hematological and radiographic outcomes of PMMA with intramedullary titanium K-wire fixation versus titanium K-wire fixation alone in avian long bone fractures, hypothesizing that combined fixation accelerates healing, reduces complications and improves functional recovery.

MATERIALS AND METHODS

Ethical approval

The study was approved by the Institutional Animal Ethics Committee, College of Veterinary Science & A.H., Jabalpur, M.P.

Animals

The study was conducted for six months from May 2024 to October 2024 in which twelve birds (wild, domestic and pet species) irrespective of species, age, gender or weight, presenting with long bone fractures. Birds were randomly allocated to Group I and Group II using a simple randomization procedure. Group I was Open reduction and intramedullary pinning with titanium K-wire while group was Open reduction and intramedullary pinning with titanium K-wire and polymethylmethacrylate. Radiographs were taken of affected limbs in two orthogonal views.

Patient preparation and anaesthesia

Pre-operative stabilization consisted of warm normal saline (10-20 ml/kg SC), Meloxicam (0.5 mg/kg IM) and Ceftriaxone sodium (50-100 mg/kg IM). Butorphanol tartrate (1 mg/kg IM) was administered 30 minutes before induction. Pre-oxygenation with oxygen (0.5-1 L/minute for 1-2 minutes) preceded mask induction with isoflurane (3-5%) and oxygen (1 L/min). Endotracheal intubation with uncuffed tubes was performed for birds >200g, secured to the mandible with micropore tape. Anesthesia was maintained with isoflurane (1.5-2.5%) via non-rebreathing Bain's pediatric circuit.

Surgical procedure

Feathers around the surgical site were gently removed after moistening with lukewarm water and surgical site was prepared aseptically. Different long bones were approached via established surgical approaches: humerus—dorsal (proximal third) or ventral (distal two-thirds); radius-ulna—dorsal; femur—lateral; tibiotarsus—craniomedial; tarsometatarsus—medial. Birds were positioned in appropriate recumbency based on surgical approach and fracture location. Following fracture visualization and debridement of devitalized tissue, PMMA preparation (for Group II only) involved mixing 2 grams of antibiotic-impregnated PMMA powder with 1 ml liquid monomer to semi-solid consistency. Using a syringe, PMMA was injected into medullary cavities of both fractured bone segments. Cold normal saline flushing was immediately performed to prevent thermal damage from exothermic polymerization. Bone fragments were aligned and reduced. Retrograde intramedullary pin placement was performed under C-arm guidance. Surgical closure done layer by layer.

Post-operative management

Post-operative bandaging provided fracture immobilization: lightweight bandages with or without splints (lightweight wooden splints) for limb fractures; Y-shaped bandaging (wing flexed) for humerus fractures; figure-of-eight bandages (wing flexed) for radius-ulna fractures. Bandages were changed every 3 days until palpable hard callus formation. Psittacine birds received custom-made Elizabethan collars to prevent self-trauma.

Antiseptic dressing was performed. Post-operative medication included Ceftriaxone sodium (50-100 mg/kg IM) for 7 days and Meloxicam (0.5 mg/kg IM) for 3 days. Passive range-of-motion (PROM) exercises were conducted twice weekly. Implants were removed 4-6 weeks post-operatively.

Parameters of study

Pre-operative and post-operative radiographs (days 0, 7, 21 and 45) were analyzed using scoring system in table 1 as per Hayashi *et al.* (2008). Lameness assessment score shown in table 2 for birds (Hatt *et al.* 2007). Hematological estimation was aseptically collected on day 0 and day 7 from basilic vein, medial metatarsal vein or right jugular vein into EDTA vials. Parameters estimated hemoglobin (g/dL), total erythrocyte count (TEC, $\times 10^3$/L), packed cell volume (PCV %), total leukocyte count (TLC, $\times 10^3$/L) and differential leukocyte count Natt and Herrick (1952).

Overall functional recovery was usage was categorized using classification devised by Kumar *et al.* (2012) shown in table 3 and Post-operative complications were recorded.

Table 1: Radiographic evaluation of fracture healing in birds

Score	Interpretation
0	Presence of recent fracture with no bone formation
1	Irregularity at fragment lines of fracture site
2	Initial/discrete periosteal proliferation
3	Exuberant/organized periosteal proliferation
4	Exuberant osseous callus in evolution with presence of periosteal proliferation
5	Exuberant osseous callus in evolution and discrete radiolucent line at gap between the fracture fragments
6	Exuberant osseous callus and absence of radiolucent line

Table 2: Lameness assessment score for birds

Score	Degree of lameness
0	Normal leg or wing function
1	Subtle, intermittent weight-bearing lameness or wing droop
2	Subtle, consistent weight-bearing lameness or wing droop
3	Obvious weight-bearing lameness or wing droop
4	Intermittent non-weight-bearing lameness or wing droop
5	Consistent non-weight-bearing lameness or wing droop

Table 3: Score card for evaluating overall functional recovery after fracture repair

Scores	Assessment
Very good	Normal fracture healing or good joint stability with normal limb usage
Good	Normal fracture healing or good joint stability but slight lameness persistence
Satisfactory	Fracture healing with slight malunion/ delayed union/ reduced joint mobility, leading to visible lameness
Unsatisfactory	Fracture failed to heal or joint unstable due to fixation failure or infection

RESULTS

During May-October 2024, 6,863 animals were registered, of which 182 presented with fractures, yielding an overall fracture incidence of 2.65%. Avian fractures accounted for 27 cases (14.83% of total fractures). Among avian patients, hind limb fractures were most common (62.96%, *n*=17), followed by wing fractures (25.92%, *n*=7). Specific bone involvement showed tibiotarsus most affected (44.44%, *n*=12), followed by radius-ulna (18.52%, *n*=5), humerus (14.81%, *n*=4), femur (7.41%, n=2) and tarsometatarsus (3.71%, *n*=1). Simple / closed fractures were more prevalent which is 8 out of 12 (66.66%) and compound / open fractures which is 4 out of 12 (33.34%). Mid-diaphyseal fractures predominated (66.66%), followed by proximal third (16.67%) and distal third (16.67%).

Clinical and orthopaedic findings

Pre-operative temperatures (°F) ranged from 102.1°F to 106.1°F (mean: Group I 104.42±0.29°F; Group II 104.28±0.49°F), within normal physiological limits with no significant difference between group. Birds presented with pain and functional impairment. Wing fractures manifested as wing drooping, open wounds, inflammation, edema and bruising. Hind limb fractures presented with unequal weight bearing.

Radiographic evaluation of fracture healing

Mean radiographic scores at successive time intervals demonstrated significantly ($P<0.05$) higher scores in Group II on days 7, 21 and 45 compared to Group I, indicating accelerated callus formation and fracture bridging. Group II demonstrated more rapid healing progression. On day 0, Group II showed higher baseline scores reflecting PMMA radiopacity. By day 7, Group I showed initiation of periosteal proliferation; Group II showed more organized callus response. By day 21, Group I demonstrated exuberant periosteal proliferation; Group II showed callus evolution with bridging. By day 45, Group I achieved near-union; Group II demonstrated complete healing with no radiolucent lines shown in table 4, Fig. 1 and 2.

Lameness scores and functional recovery

Lameness scores showed significant ($P<0.05$) progressive reduction in both groups. Group II demonstrated significantly ($P<0.05$) lower lameness scores on days 7, 21 and 45 compared to Group I. Group II achieved functional recovery approximately 1-2 weeks earlier than Group I. Group II birds demonstrated weight-bearing initiation by days 7-14; Group I required 21+ days. By day 45, 50% of Group II birds exhibited completely normal gait; 33.33% showed minimal limp; 16.67% showed mild limp. Group I birds showed 16.67% normal gait; 33.33% minimal limp; 33.33% mild limp; 16.67% persistent moderate limp (due to non-union) shown in table 5.

Table 4: Mean (±SE) value of radiographic score at different time intervals in birds

Group	**Mean ± SE**			
	Day 0	**Day 7**	**Day 21**	**Day 45**
Group 1	00 ± 00	$1.66^{b} \pm 0.55$	$3.66^{a} \pm 0.47$	$4.33^{a} \pm 0.65$
Group 2	00 ± 00	$3.33^{c} \pm 0.21$	$5.16^{b} \pm 0.16$	$5.66^{b} \pm 0.21$
t- value (p≤0.05)	—	-2.795*	-3.021*	-1.947*

Note: Mean values within the same group with different superscripts (a, b, c and d) differed significantly (p≤0.05) at different time intervals, * Significant at 0.05 level between groups.

Table 5: Mean (±SE) value of lameness score at different time intervals in birds

Group	**Mean ± SE**			
	Day 0	**Day 7**	**Day 21**	**Day 45**
Group 1	$3.16^{a} \pm 0.30$	$2.33^{ab} \pm 0.42$	$1.50^{ab} \pm 0.56$	$1.00^{b} \pm 0.51$
Group 2	$2.83^{a} \pm 0.31$	$1.83^{ab} \pm 0.42$	$1.33^{b} \pm 0.21$	$0.50^{b} \pm 0.22$
t- value (p≤0.05)	0.767	0.958*	0.277*	0.889

Note: Mean values within same group with different superscripts (a, b, c and d) differed significantly (p≤0.05) at different time intervals, * Significant at 0.05 level between groups.

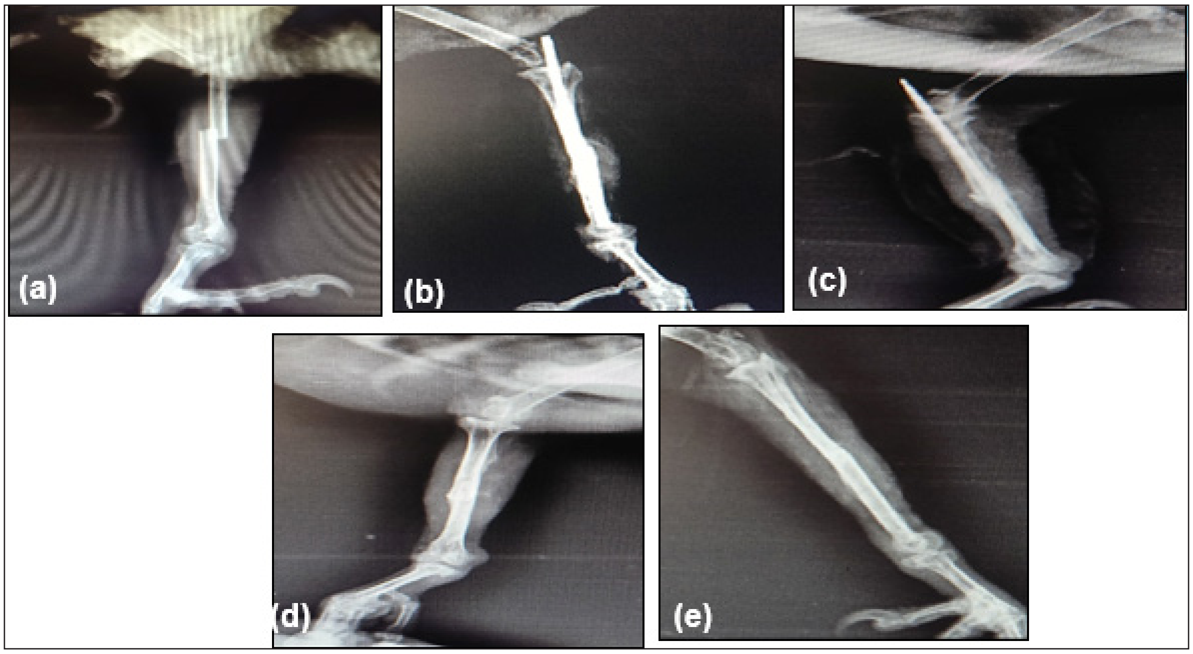

Fig. 1: Radiographs of group I; **(a)** Pre-operative **(b)** After surgery **(c)** day 7 **(d)** day 21 (after pin removal) **(e)** day 45

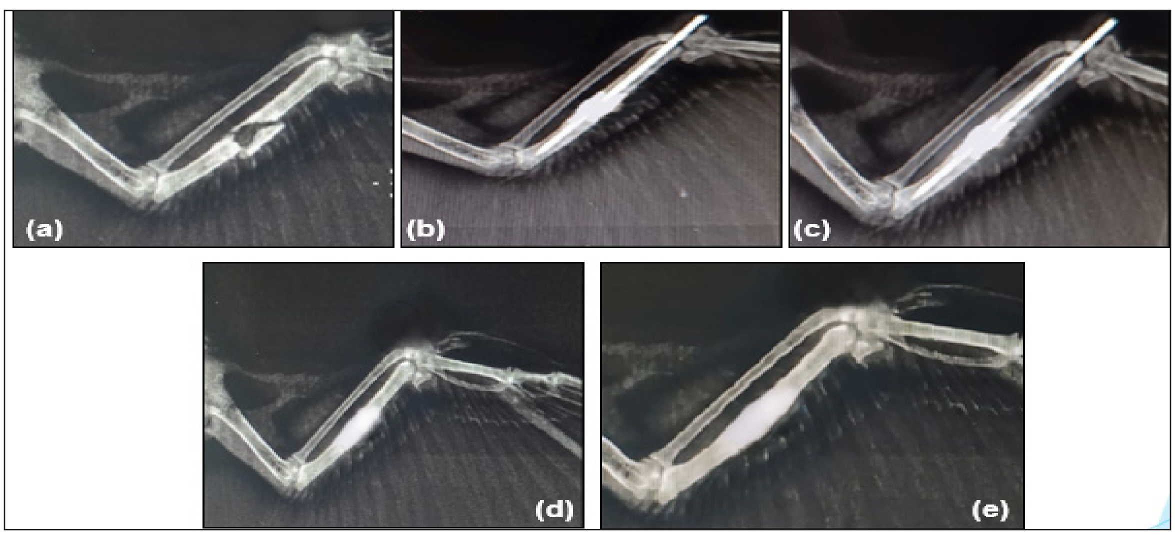

Fig. 2: Radiographs of group II; **(a)** Pre-operative **(b)** After surgery **(c)** day 7 **(d)** day 21 (after pin removal) **(e)** day 45

Overall functional recovery assessment post-implant removal showed Group II achieved superior outcomes: 83.33% (5/6 birds) achieved very good to good recovery versus 66.67% (4/6) in Group I. Zero unsatisfactory outcomes in Group II versus 16.67% (1/6) in Group I, Fig. 3 and 4.

Hematological findings

Hemoglobin total erythrocyte count (TEC) and packed cell volume values remained within normal physiological range.

TLC decreased significantly ($P<0.05$) in Group I, but the decrease in Group II was not statistically significant

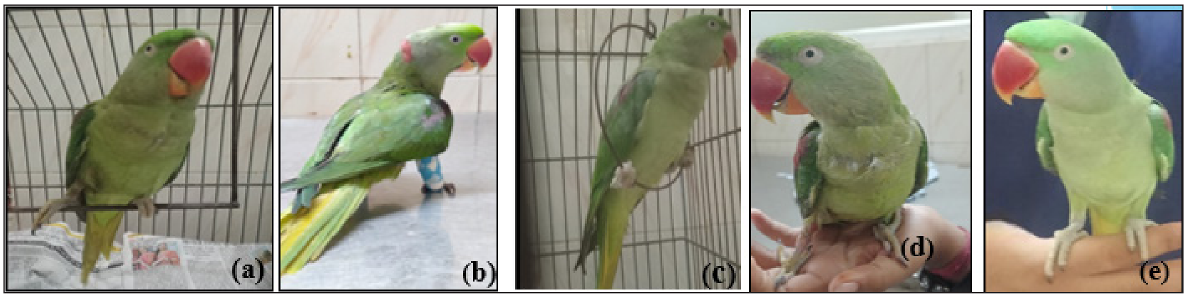

Fig. 3: Wing function of a bird in group I; **(a)** Pre-operative **(b)** After surgery **(c)** day 7 **(d)** day 21 pin removal) **(e)** day 45

Fig. 4: Wing function of a bird in group II; **(a)** Pre-operative **(b)** After surgery **(c)** day 7 **(d)** day 21 pin removal) **(e)** day 45

(Group I: 20.46±1.52 to 15.68±0.70 $\times 10^3$/L; Group II: 15.60±1.80 to 12.65±0.37 $\times 10^3$/L). Day 0 elevation reflects inflammatory response to trauma and surgical intervention and significant reduction on day 7 indicates diminishing inflammatory stimulus with improved tissue healing. Higher initial TLC in Group I may reflect greater operative trauma.

Heterophil Count decreased significantly ($P<0.05$) from day 0 to day 7 (Group I: 72.33±3.64 to 62.33±2.74%; Group II: 66.83±1.07 to 58.16±0.65%). Heterophilia reflects acute inflammatory response to trauma, pain, restraint and surgical stress. Significant reduction by day 7 indicates diminishing acute inflammatory state and pain resolution.

Lymphocyte count increased significantly ($P<0.05$) from day 0 to day 7 (Group I: 22.16±3.82 to 32.50±2.69%; Group II: 27.66±0.98 to 37.16±0.90%). Lymphopenia during acute injury reflects stress-induced lymphocyte sequestration; recovery indicates resolution of acute stress phase and transition to repair. Increased lymphocytes represent normal immune response during tissue healing and callus formation.

DISCUSSION

The fracture incidence of 2.65% in all animals and 15.54% in avian cases aligns with published veterinary literature Pramod *et al.* (2021). The predominance of hind limb fractures (62.96%) in avian patients reflects the biomechanical demands on hindquarters during perching and landing Sindhu *et al.* (2023). Tibiotarsus involvement (44.44%) is consistent with studies on wild and captive bird injury patterns Pramod *et al.* (2021).

PMMA's role as a rigid luting agent enhances fracture site stability by filling medullary cavity interstices, reducing micromotion and pain at fracture interfaces. The superior radiographic progression in Group II reflects PMMA's ability to facilitate endosteal callus formation and bridging, consistent with biomechanical principles of rigid internal fixation Kaveh *et al.* (2024). The radiopacity of PMMA may partially influence radiographic scoring, particularly at early time points, by increasing apparent density at the fracture site. This could potentially lead to overestimation of healing on plain radiographs compared to K wire alone. Our interpretation of radiographic scores therefore considered the possibility of this bias and we emphasize that clinical and functional outcomes should be evaluated alongside radiographic findings

Lameness assessment revealed clinically significant advantages in Group II. Group II birds demonstrated weight-bearing initiation 1-2 weeks earlier than Group I, indicating superior early functional recovery. By day 45, 50% of Group II birds exhibited completely normal gait compared to only 16.67% in Group I. These findings correlate with radiographic scores, demonstrating that improved radiographic healing translates to earlier functional recovery and pain resolution.

Overall functional recovery was superior in Group II: 83.33% achieved very good to good outcomes versus 66.67% in Group I. This difference reflects PMMA's biomechanical advantages in reducing micromotion, accelerating callus formation and enabling earlier rehabilitation. The absence of unsatisfactory outcomes in Group II versus 16.67% in Group I further supports the combined fixation technique.

Hematological findings revealed successful post-operative recovery and controlled inflammatory response. Total leukocyte count elevation on day 0 reflected expected inflammatory response to trauma and surgical intervention. Significant reduction by day 7 in both groups indicates effective pain management, antibiotic therapy and surgical technique. The pattern of heterophil decrease and lymphocyte increase represents resolution of acute inflammatory phase and transition to adaptive immune response and supporting tissue healing progression Thrall *et al.* (2012). Complications were significantly fewer in Group II (16.67%) compared to Group I (33.34%). Pin migration in Group I occurred in 1 bird (16.67%), resulting from inadequate rotational control with titanium K-wire alone—a known limitation of simple intramedullary pinning in thin-corticated avian bones Kothamdi (2014). PMMA's rigid luting properties prevented proximal migration by creating mechanical interlock between pin and medullary cavity.

Intramedullary techniques and PMMA use may pose a risk of bone marrow injury or altered marrow microenvironment, with possible delayed hematological or immunological consequences. Our follow-up period and sampling schedule were not designed to detect long term marrow or systemic effects, which represents an important limitation. Future studies with extended follow-up and more detailed hematological or immunological monitoring are warranted to address these potential risks.

GENERATIVE AI DECLARATION

The author(s) confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript, and no images were manipulated using AI. The authors developed and verified all scientific content, data analysis, interpretation of results, and conclusions. The authors take full responsibility for the accuracy, integrity, and originality of the work presented, and no AI tool was listed as an author.

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