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RESEARCH ARTICLE

Distraction Osteogenesis by Ring Fixator in Post Traumatic Tibial Bone Loss

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Abstract
Background: Reconstructing segmental bone loss defects presents a significant challenge within the field of orthopedics. The purpose of this study is to assess the clinical and radiological results of using the Ilizarov technique for tibia reconstruction following traumatic bone loss. Methods: This study was a prospective study involving 30 patients who experienced tibial bone loss in the diaphysis or metaphysis following trauma. These patients were treated with a ring fixator (Ilizarov) from March 2021 to February 2023. Unfortunately, five patients were lost to follow-up, leaving a cohort of 25 patients who were observed for a duration ranging from 9 to 12 months. Results: The current study involved 25 patients with post-traumatic tibial bone loss. The age range was 14 to 48 years, with a mean age of 28.4±8.8 years. Among the cases, 18 had a moderate defect (72%), which was significantly higher than those with a minor defect (20%) ($P \leq 0.05$). Deformity was less than 7° in most cases (96%), while only one case had deformity greater than 7° (4%) ($P \leq 0.05$(. Leg length discrepancy was less than 2.5 cm in the majority (96%), with only one case having a 3 cm length discrepancy (4%) ($P \leq 0.05$). By the end of the follow-up period, all patients showed perfect union, enabling them to engage in daily activities post-operatively. Conclusion: The success of corticotomy and solid docking relies on well-vascularized bone and soft tissue. Soft tissue compromise at the corticotomy site can hinder healthy tissue regeneration.

Keywords
Distraction Osteogenesis, Ring Fixator, Tibial Bone Loss

INTRODUCTION

Bones have an inherent ability to naturally heal after an injury. However, in specific critical-sized defects, the bone's self-healing capacity is insufficient, necessitating medical intervention (Dimitriou et al., 2011).

Various methods are accessible for addressing these defects, including the widely accepted autogenous bone grafts, allografts, bone graft substitutes, and vascularized fibular bone grafts. Nevertheless, it's important to note that all these techniques come with their own set of limitations (Nauth et al., 2011).

Signs of clinical issues, whether vascular or related to soft tissue, only become evident when shortening exceeds 2 cm (Edwards, 1983). Treating tibial bone and soft tissue defects, particularly those larger than 5 cm, resulting from high-energy trauma or non-union debridement, poses a substantial challenge for orthopedic surgeons regarding both limb reconstruction and soft tissue coverage. The Ilizarov method has brought about a significant transformation in the management of these injuries, to the extent that some experts consider it the benchmark for addressing tibial bone defects through distraction

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osteogenesis (Fürmetz et al., 2016, Zhang et al., 2018).

The Ilizarov technique is valuable in various clinical scenarios, spanning across pediatric and adult patients, even though its most common application remains the correction of limb length disparities and complex deformities (Foster et al., 2012, Dickson et al., 2015).

In comparison to alternative methods for rectifying posttraumatic angular deformities, such as intramedullary nails, plate fixation, and osteotomies, the Ilizarov method has more straightforward surgical objectives. Surgeons are primarily responsible for ensuring stable fixation for each bone segment and performing an osteotomy (Marcellin-Little, 1999).

The alignment of the limb is determined while the patient is under anesthesia and not bearing weight, which introduces an element of unpredictability in terms of the functional and cosmetic results of the surgery. This unpredictability may necessitate additional procedures to achieve full deformity correction (Marcellin-Little, 1999).

The aim of this prospective study was to evaluate clinical and radiological outcome of ilizarov technique for reconstruction of tibia in post-traumatic bone loss.

MATERIALS AND METHODS

Study Design

In a prospective study spanning from March 2021 to February 2023, 30 patients with tibial bone loss in the diaphysis or metaphysis, following trauma, were treated using a ring fixator (Ilizarov). Unfortunately, five patients were lost to follow-up, leaving 25 patients who were tracked for a duration ranging from 9 to 12 months. Of these, 10 patients received their treatment at Beni Suef University Hospital, while the remaining 15 were treated at Nasser Institute Hospital.

This study followed ethical standards and received approval from the Faculty of Medicine Beni-Suef University with reference number (FMBSUREC/03012021/04.09.2023). Participant provided informed consent, with the volunteer form covering research details, risks, benefits, confidentiality, and participant rights. The research strictly adhered to the ethical principles of the Declaration of Helsinki, prioritizing participant's rights and well-being in design, procedures, and confidentiality measures.

Inclusion criteria were patients under 50 years old with post-traumatic tibial fractures, including 10 patients with bone defects resulting from the initial trauma and 15 patients with defects arising from repeated debridement following septic and aseptic nonunion. **Exclusion criteria were** patients over 50 years old, those with neurovascular insufficiency, individuals with pathological fractures due to bone tumors, and those with comorbidities that might interfere with anesthesia or healing, such as cardiac issues or uncontrolled diabetes.

The clinical assessment involved a thorough history, general and local physical examinations, with a particular focus on the condition of the skin and soft tissues in areas where transosseous wires and screws were applied. Laboratory investigations included CBC, ESR, CRP, and routine preoperative tests.

Radiological assessments consisted of plain x-ray views from the anterior-posterior and lateral perspectives, computed tomography, and a CT scanogram to evaluate limb length in cases of bone loss.

Operative planning:

The operative planning phase encompassed anesthesia, the patient's positioning on the operating table, the application of a tourniquet, and preoperative landmarks, and surgical procedures.

Surgical technique:

The surgical technique involved the resection of necrotic bone until bleeding, known as the "paprika sign," was observed **(Fig. 1 A)**. The area was irrigated with saline, and the defect length was assessed based on Robinson et al.'s classification (Robinson et al., 1995). If the fibula was intact, a proximal reference wire was positioned perpendicular to the mechanical axis of the tibia and connected to the proximal ring, while the distal reference wire was aligned parallel to the ankle joint and connected to the distal ring. The middle bone segment was secured with wires to the middle ring, and half-pins were used to enhance stability in each segment.

Tibial alignment was checked using imaging. Shortening was carried out while monitoring the vascularity of the dorsalis pedis and tibialis posterior. If there was a short distal bone segment, the ankle joint was spanned, and an osteotomy was performed at the metaphyseal-diaphyseal junction using a pre-drilled hole (corticotomy). The periosteum was preserved and closed after osteotomy. In one case where the fracture was close to the ankle joint, the foot was included in the frame to prevent equinus contracture and enhance osteosynthesis stability. Acute bone shortening, up to 3 cm, was performed without complications, using a T or Z-shaped incision to avoid skin issues during closure (Fig. 1 B).

For lengthening, distraction was initiated at a rate of one millimeter per day after a latency period of 10 days, and daily cleaning with saline was performed. At the end of the follow-up period, bone and functional outcomes were assessed using the Association for the Study and Application of the Method of Ilizarov (ASAMI) scoring system (Testa et al., 2020).

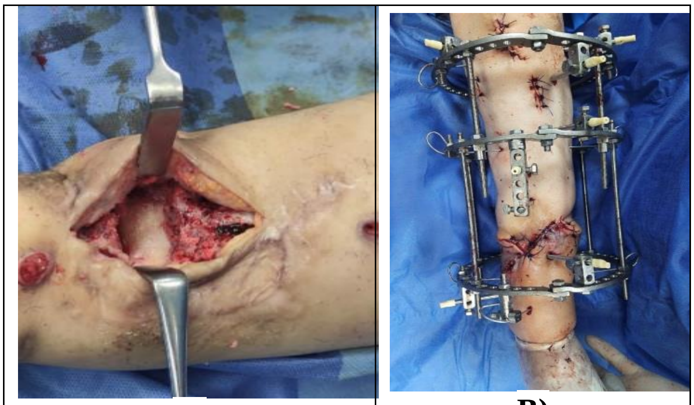

A) B)

Figure 1. A) Paprika sign and B) Z shape incision

Statistical analysis

Historical data, basic clinical examinations, and outcome measures were collected and subsequently coded, entered, and analyzed using Microsoft Excel software. The data was then transferred to Statistical Package for the Social Sciences (SPSS version 21.0) for further analysis. Qualitative data were represented in terms of numbers and percentages, while quantitative data for continuous groups were expressed as mean ± standard deviation. To determine the significance of differences, the following tests were employed: for qualitative variables, the Chi-square test (X2) was used to assess differences and associations, while for quantitative independent groups, the t-test was employed. A significance level of <0.05 indicated statistically significant results.

RESULTS

The study group comprised 25 patients with post-traumatic tibial bone loss, consisting of 20 males (80%) and 5 females (20%). The patients' ages ranged from 14 to 48 years, with an average age of 28.4±8.8 years (Table 1).

Table 1. Demographic data of the study group

Demographic data		**Study group** (n=25)
Sex	Males	20 (80%)
	Females	5 (20%)
Age (year)		28.4±8.8 / 14-48

Data were presented as mean ± standard deviation (SD), number (%).

In the context of osteomyelitis, a significant majority of cases showed no postoperative deep infection (96%), whereas only one case (4%) experienced an infection ($P \leq 0.05$) that was successfully resolved through surgical debridement (Table 2).

Table 2. Postoperative deep Infection in the study group.

Postoperative Deep Infection	**Study group** (n=25) N	%
Yes	1	4
No	24	96
Chi square	21.160	
P-value	< 0.0001*	

***P** ≤ 0.05 is considered significant

In terms of deformity, a significant majority of cases (96%) exhibited deformities of less than 7°, while only one case (4%) showed a varus deformity exceeding 7° ($P \leq 0.05$). Notably, the patient with the varus deformity expressed satisfaction with the outcome (Table 3)

Table 3. Deformity in the study group

Deformity <7 °	**Study group** (n=25) N	%
Yes	24	96
No	1	4
Chi square	21.160	
P-value	< 0.0001*	

***P** ≤ 0.05 is considered significant

In terms of leg length discrepancy, a significant majority of cases (96%) had a difference of less than 2.5 cm, while only one case (4%) had a discrepancy of 3 cm ($P \leq 0.05$). It's worth noting that this discrepancy did not affect

Table 4. Leg length discrepancy (LLD) in the study group

LLD <2.5 cm	**Study group** (n=25)	
	N	%
Yes	24	96
No	1	4
Chi square	21.160	
P-value	< 0.0001*	

***P ≤ 0.05 is considered significant**

A significant majority of cases (96%) did not experience a loss of ankle motion, while only one case (4%) had a stiff ankle (P ≤ 0.05). The issue in this case was attributed to a short distal tibial bone segment, leading us to utilize a spanning ring for long-term support. By the end of the follow-up period, the patient had achieved full bone union and chose not to undergo further operations (Table 5).

Table 5. Loss of ankle motion in the study group

Loss of ankle motion	**Study group** (n=25)	
	N	%
Stiff	1	4
No	24	96
Chi square	21.160	
P-value	< 0.0001*	

***P ≤ 0.05 is considered significant**

There was an insignificant association between ASAMI and Robinson classifications for orthopedic limb defects in the study group (P-value = 0.3676) (Table 6).

Table 6. Relation between ASAMI classification and Robinson classification defect in the study group

ASAMI classification	**Robinson classification defect**			
	Minor (<2.5cm)		**Moderate (2.5-10cm)**	
	N	%	N	%
Excellent	7	100	16	88.9
Good	0	0	2	11.1
Chi square	0.812			
P-value	0.3676			

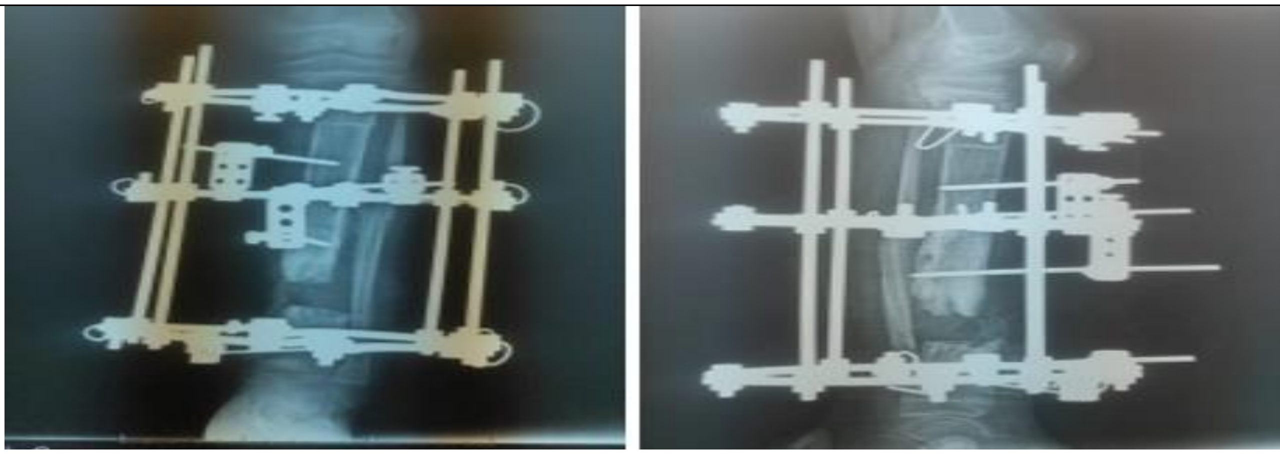
No significant relation was found between ASAMI classification and Robinson classification defect (P.>0.05).

Case Presentation

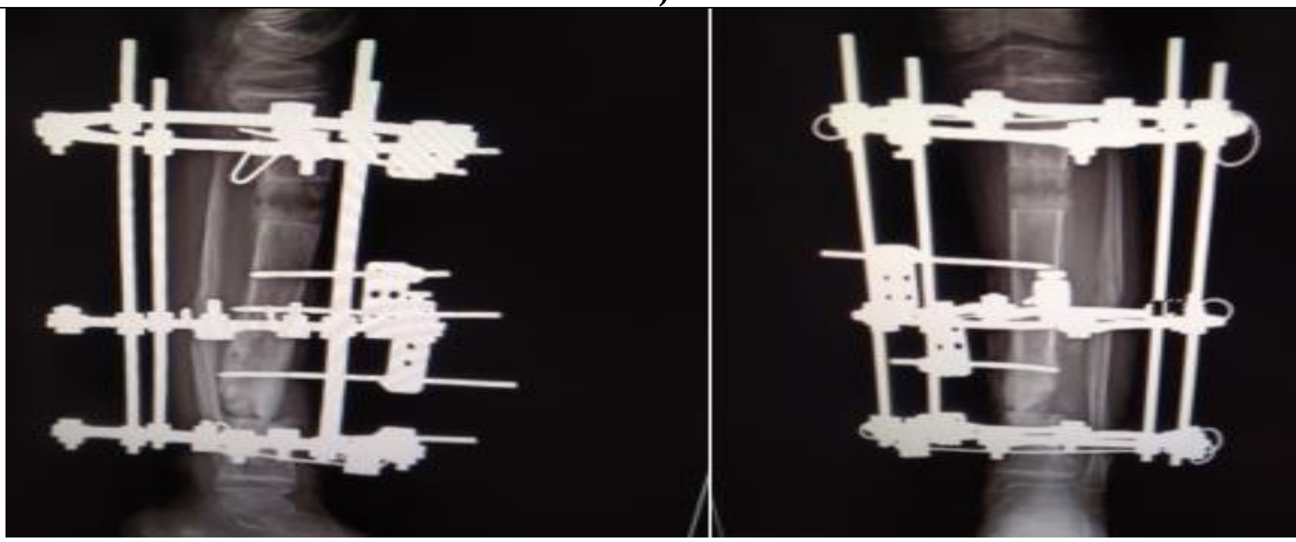
We describe a 14-year-old male patient with a 4 cm left tibia defect classified as moderate per the Robinson classification. This bone defect resulted from post-infection nonunion debridement after the failure of a previous plate and screws procedure. The treatment approach involved single-level bone transport using the Ilizarov technique following bone debridement, with a distraction rate of 0.25 mm every 6 hours per day for six weeks until the docking site was achieved. The patient was followed up for a duration of 9 months, and the outcome, as per the ASAMI Classification, was rated as excellent (Fig. 2,3,4)

A)

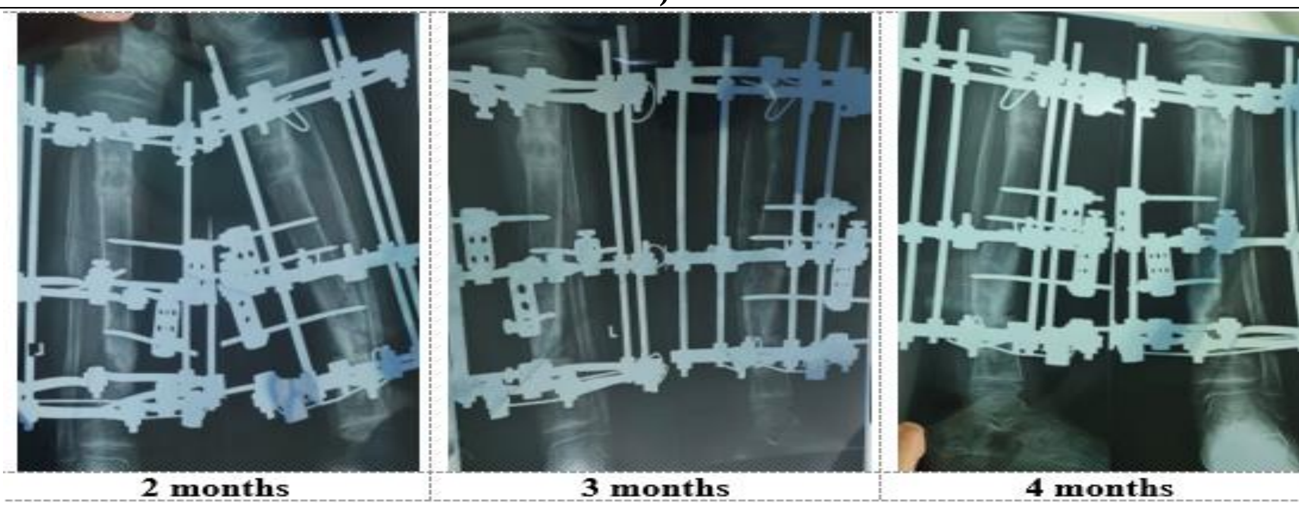
Figure 2. A) AP and lateral X-rays of left distal tibia infected nonunion with sequestrated bone, left one clinical photo.



B)



C)



D)

Figure 3.
B) AP and lateral postoperative X-rays of lift distal tibia with single level bone distraction after bone debridement using ring fixator.
C) X-rays of postoperative follow up at 1 month post bone distraction left tibia with single level bone transport.
D) X-rays of postoperative left tibia with bone distraction.

E)

F)

Figure 4.
E) Full weight bearing with flexion knee and mobile ankle joint.
F) AP and lateral X-rays of left tibia with single bone distraction follow up post removal of ilizarov level and single level bone distraction

DISCUSSION

Segmental bone loss remains a persistent challenge for orthopedic surgeons, particularly in the context of trauma, often resulting from open fractures and infections. The tibia, in particular, is the most commonly affected site in cases of traumatic bone loss, primarily due to its limited soft tissue coverage, which increases the risk of open fractures and bone extrusion in high-energy injuries. While there are several surgical methods available for addressing these complex cases, a lack of consensus or specific guidelines for comprehensive management continues to be a notable issue, leading to potential obstacles in achieving favorable long-term functional outcomes due to the relatively high occurrence of complications and subsequent reoperations (Adamczyk et al., 2020).

In our study, our patient group consisted of 10 individuals who experienced post-traumatic tibial bone loss resulting from initial trauma. Among these, eight patients underwent bone transport with an Ilizarov ring fixator to address moderate bone loss ranging from 2.5 to 10 cm, while the remaining two patients opted for acute bone shortening with gradual lengthening using an Ilizarov fixator to manage minor bone loss, measuring less than 2.5 cm. The differentiation between these approaches was based on the Robinson classification for bone defects. For patients with post-traumatic bone loss due to infected nonunion, our study included 15 cases. Ten of them were treated with bone transport employing an Ilizarov ring fixator to address moderate bone loss (2.5 - 10 cm), while the remaining five patients underwent acute bone shortening with gradual lengthening via an Ilizarov fixator to manage minor bone loss, again categorized according to the Robinson classification.

In comparison, a study by Sen C et al. focused on 24 cases of post-traumatic tibial bone loss with moderate bone defects, addressing them through bone transport with the Ilizarov method (Sen et al., 2004). Meanwhile, Krappinger D et al. examined 15 cases with larger post-traumatic tibial bone defects, ranging from moderate to severe loss, which were also managed using the Ilizarov method (Krappinger et al., 2013).

In our study, all patients achieved successful union at the docking site. This was achieved through various techniques, including bone marrow injection in seven patients, refreshing bone ends with bone compression in six patients, and the use of iliac bone graft in two patients. In contrast, in Magadum MP et al.'s research, they found that only one patient experienced nonunion (Magadum et al., 2006). In our own study, the timing of Ilizarov frame removal after achieving union varied, ranging from 6 to 11 months. This duration decreased when we employed acute compression with gradual lengthening and the bifocal bone transport technique. However, the effectiveness of this approach was limited in cases where there was an insufficient amount of proximal or distal bone segments available for a double-level osteotomy, along with the challenge of ensuring adequate soft tissue coverage. The timing for frame removal increased as the size of the bone defect and the chosen technique in the study became more extensive. In contrast, Sen C et al. reported a mean external fixation duration of 7.1 months (range 3-10) due to their use of the bifocal bone transport technique. The follow-up period for our patients ranged from 9 to 12 months.

By comparison, Sen C et al. conducted a study with a longer follow-up duration, extending to 18-60 months, and Magadum MP et al.'s study had a follow-up period of 39 months (Magadum et al., 2006). This difference in follow-up duration could be attributed to the complexity of cases and the need for multiple surgeries in the patients.

In our study, both bone and functional outcomes were evaluated using the ASAMI scoring system. The results revealed excellent outcomes in 23 cases (92%), which was significantly higher than the percentage of cases with good outcomes (8%) ($P \leq 0.05$). These findings were consistent with Sen C et al.'s study, where 21 patients achieved excellent results, and three had good results (Sen et al., 2004). Furthermore, in our study, the majority of patients did not experience deep infections (96%), with only one case suffering from a deep infection (4%) ($P \leq 0.05$), which was successfully resolved through surgical debridement. In contrast, Magadum MP et al.'s study reported a higher rate of postoperative infections, with 21 patients experiencing minor pin tract infections during the treatment period, involving an average of 5 pin sites per patient. Four patients developed moderate to severe pin tract infections (Magadum et al., 2006).

Additionally, in our study, most patients had leg length discrepancies of less than 2.5 cm (96%), with only one case having a 3 cm difference (4%). This discrepancy did not significantly affect their daily activities, and the patient declined further surgical interventions. Dendrinos GK et al.'s study also successfully corrected deformities and length discrepancies to less than 7 degrees and 2.5 centimeters, respectively (Dendrinos et al., 1995). Moreover, in our study, at the end of the follow-up period, the majority of cases had angulations of less than 7° (96%), with only one case having an angulation exceeding 7° (4%) ($P \leq 0.05$), and this patient expressed satisfaction. In contrast, Magadum MP et al.'s study reported two patients with minor residual deformities (Magadum et al., 2006).

Finally, in our study, most cases showed no loss of ankle motion (96%), with only one case experiencing a stiff ankle (4%) ($P \leq 0.05$). This issue was attributed to a short distal tibial bone segment, which led us to use a spanning ring for long-term support. By the end of the follow-up period, the patient had achieved full bone union and declined further surgical interventions. These findings were consistent with Magadum MP et al.'s study, where one patient had a 10° fixed flexion deformity but still maintained the ability to perform daily activities postoperatively (Magadum et al., 2006).

Conclusions

The success of both corticotomy and solid docking hinges on well-vascularized segments of bone and soft tissue. When the soft tissue is compromised at the intended corticotomy site, the development of healthy regenerate tissue may be impeded. Severe open fractures with a wide zone of injury are frequently linked to inadequate soft tissue coverage at the injury site.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Ethics Committee

This study followed ethical standards and received approval from the Faculty of Medicine Beni-Suef University with reference number (FMBSUREC/03012021/04.09.2023).

Author Contributions

The authors accomplished this study by making significant contributions including designing the study according to the formulation of its objectives. AGM, AABAS prepared the draft and carried out the study design; AGM, AMS and HGHG collected the data; AGM, AABAS and HGHG performed the statistical analysis of the data; AGM, AABAS and HGHG interpreted the data; and all authors of the manuscript performed the literature search and collaborated on the manuscript critical review and editing. All authors were contributors and responsible for the content of the manuscript and approved the version submitted for publication.

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