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Long-term Results of Single-stage Minimally Invasive Surgery of Pilon Fractures

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Abstract

Objective: The purpose of this study was to assess the technical specifications and long-term results of "early minimally invasive surgery" that we have been implementing on AO 43-C3 pilon fractures.

Methods: Twelve patients with AO 43-C3 closed fracture were operated within the first 36 h of trauma with the goal of providing definitive treatment. After consideration of the associated fibular fracture, tibial articular surface was fixed with anatomical reduction and rigidly percutaneously. Subcutaneous anatomical medial plating was applied to provide relative stability between articular block and the comminuted metaphyso-diaphyseal part.

Results: The average age was 50 (range: 36-62) years. The average time between trauma and surgery was 18 (range: 6-36) hours. The average follow-up period was 60 (range: 24-78) months. There were no wound problems or infections. The reduction quality was excellent in 7 patients and good in 5 patients. Clinical results were excellent for 4 and good for 8 patients. Stage 1 arthrosis was observed in 4, stage 2 in 6, and stage 3 arthrosis in 2 patients.

Conclusion: Single-stage minimally invasive plating of AO 43-C3 pilon fractures may result in a satisfactory functional score in the long term because of the quality of joint reduction and the effect of the energy load of the trauma, which is important for the development of arthrosis.

Keywords: Pilon, mipo, tibia, fracture

INTRODUCTION

The treatment of pilon fractures presents technical challenges, and clinical results may remain below expectations. The intensity of the energy causing the trauma and its impact on the extremity determines the fracture type and the damage inflicted on the soft tissue (1,2). Treatment choice is dependent on the soft tissue condition and the type of the fracture, which also affect results. Infections and soft tissue coverage problems have been observed on single-stage open fracture restoration attempts (2,3). With the development of staged operative reduction and internal fixation techniques, infection and soft tissue problems have decreased remarkably (1,4).

With the development of low-profile plates and the use of indirect reduction techniques, staged open surgeries have evolved into staged minimally invasive surgery (5,6). Unfortunately, delayed definitive reduction and fixation frequently results in challenged reduction due to fibrosis between fragments (7).

Considering the easier reduction of fractured fragments at an early stage, which reduces the pressure created by displaced fragments and thus prevents soft tissue coverage issues, we examined the technical specifications and long-term effects of "early minimally invasive surgery" that we have been implementing on AO 43-C3 pilon fractures.

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Methods

The study was conducted with the permission of the Ümraniye Training and Research Hospital Clinical Research Ethics Committee (date: 15/05/2023, decision no: E-54 132726-000-215611251). The authors read the Helsinki Declaration and approved ethical obligations for the study. Informed consent was obtained from all patients. Closed AO 43-C3 fractures were included in the study, which were treated by minimally invasive medial plating within 36 hours of trauma. Open fractures, AO 43-A/B/C1/C2 fractures and staged surgeries were excluded. Twelve patients with AO 43-C3 closed-fracture were operated within the first 36 h of trauma with the goal of providing definitive treatment. Fibular fracture was in eight (66.6%) patients. Anteroposterior and lateral radiographs were taken from patients during submission to the clinic. A computed tomography (CT) scan of the ankle was provided for the preoperative evaluation of comminution.

Surgical Technique

1. The positioning of the patient is crucial for obtaining high-quality fluoroscopic images. During surgery, maintaining the extremity in a neutral position is crucial for preventing the loss of the achieved temporary reduction. The patients were operated under general anesthesia in the supine position. With the help of a slim pillow placed under the ipsilateral hip, external rotation of the extremity was prevented. The relevant limb was supported and elevated with the help of a hard pillow, extending from the popliteal region to the heel. Using this method, we aimed to obtain fixed angles for the anteroposterior and lateral fluoroscopic views.

2. Achieving reduction of the lateral malleolus and ensuring proper fibula length are essential for achieving the anatomical reduction of the distal tibial articular surface. To ensure the fibular length, we first applied fibular fracture reduction and fixation. Anatomic correction was provided in simple transverse fibular fractures using a percutaneous Rush pin on one patient. Two simple oblique and five comminuted fibular fractures were fixed using the bridge-plating method based on relative equilibrium principles with the help of 1/3 tubular plates (Synthes-Oberdorf) (1,8). The plates were applied through posterolateral double mini-incision. Anteroposterior and lateral fluoroscopic images were obtained for alignment control.

3. Joint distraction facilitates the manipulation of articular fragments. Therefore, unilateral external fixation was applied for indirect reduction of fractured segments on the surface of the distal tibial joint under distraction. The tibial joint was distracted by inserting 6 mm Schanz screws, 2 to 1/3 proximal tibia, 1 each to the medial part of the neck of the talus and calcaneous. Distraction performed using a unilateral external fixator from the medial side can lead to overalgization. This situation not only complicates the control of particular fragments but also subjects the identified fibula fracture to excessive loading, resulting in potential reduction loss.

4. Distal tibial articular fractures consist of three main components: the medial malleolus, Chaput fragment, and Volkmann fragment. In addition, depending on the severity of impaction, a die punch fragment can also be present (9). The Chaput fragment is a good starting point for achieving anatomical restoration of the articular surface through the length restoration of the lateral malleolus and posterior tibiofibular ligamentotaxis. The posterior part of the joint was used as the starting point for the anatomical reduction. The second important part of the joint defined as the die punch (9), which extends from the plafond center and wedges to the metaphysis, was pushed toward the joint with the help of a blunt K-wire or a thin elevator inserted in the cephalo-caudal direction. Before reducing the medial malleolus and Volkmann fragments, it is important to control the alignment of the die punch fragment with the Chaput fragment. The die punch fragment should be pushed craniocaudally using a K-wire or a thin periosteal elevator to align it with the articular surface of the Chaput fragment at the same level (Figure 1). It is crucial to lower the die punch fragment to the joint level before fixing the Volkmann and medial malleolus fragments; otherwise, compressed joint surfaces may hinder the reduction process.

5. Anterolateral, anterior, and medial fragments were reduced with the help of the K-wire joystick technique and were temporarily fixated to the posterior joint fragment with the same K-wires. Medial malleolus and Volkmann fragments were reduced with the help of the K-wire joystick technique and were temporarily fixated to the Chaput fragment with the same K-wires. At this stage, it is necessary for the Chaput and Volkman fragments to be steplessly reduced in the coronal plane and the medial malleolus and lateral joint line to be steplessly reduced in the sagittal plane. Fluoroscopic imaging was used to determine the various displacements and steps that might occur in the joint. Using frontal and sagittal fluoroscopic images, the compatibility of the tibial joint surface with the joint surface of the Talus and its anatomical fixation was targeted. Two safe screw zones were used for the fixation of the basic joint components. The first safe zone is reached by penetrating from the lateral of the extensor digitorum longus tendon and is used for fixation of the anterior or anterolateral fragment to the posterior or postomedial

part. The second safe zone is reached by penetration through the medial tibialis anterior tendon and targets the fixation of the anteromedial or medial fragment to the posterior or posterolateral part. Absolute stability was provided by the use of 4.0 mm cannulated screws sent via guidewires at safe intervals percutaneously (Figure 2).

Figure 1. Die punch fragment reduction

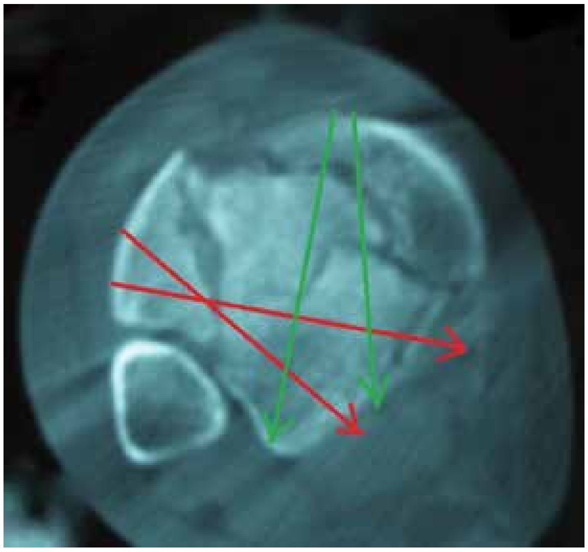

Figure 2. Axial plan, the configuration of safe-corridors for the identification of basic parts fragments. Red arrows show the anterolateral entry, the green arrows the anteromedial entry

6. The joint united by absolute equilibrium was fixed to the metaphyseal-diaphyseal section by the relative stability principle. After the fragments belonging to the joint are brought together using the lag screw technique with cannulated screws to achieve absolute stability, the next step is to proceed with the relative stabilization and fixation of the joint block with the metaphyseal-diaphyseal component (10). For this fixation, a distal medial tibial metaphyseal locking compression plate 3.5/4.4.5/5 (Synthes-Oberdorf) was applied by a subcutaneous tunnel created from a mini-incision to the medial crural region. Around the incision created over the medial malleolus, the saphenous vein and nerve are present. Proper dissection of this area and precise formation of the tunnel path for proximal subcutaneous advancement of the plate over the bone will help prevent complications such as skin compression and injury to the vein or nerve. The length of the plate was calculated as the sum of the joint unit, the metaphyseal fracture length, and the length of 5 or 6 holes over the metaphyseal fracture zone. The joint unit block was stabilized with 3.5 mm cortical or locked screws, and the diaphraseal portion was stabilized with 4.5 mm cortical and 5.0 mm locked screws (Figures 3, 4).

Postoperative Follow

An external fixator was kept in place for 10 days on our first two patients during the postoperative period to control pain and

Figure 3. Fracture fixation under distraction with the external fixator. Lateral image under flouroscopy

swelling. We eliminated the use of an external fixator in our next cases and preferred to use short-leg splints instead. At the end of the second week, we removed the external fixators or splints. Active range motion of the ankle was permitted. Anti-edema stockings were applied. Toe-tip contact (not weight bearing) was permitted from the end of the second week until the end of the sixth week. From the sixth week to the 12^{th} week, weight bearing was increased on a weekly basis as tolerated. Full weight bearing was allowed starting from week 12^{th} single crutch use was permitted 4 weeks more according to patient confidence.

Data Collection

Anteroposterior and lateral radiographs of patients were evaluated at weeks 3-6 and at their final visits. The Teeny and Wiss (2) scoring system was used for clinical evaluation. We used Conroy et al. (11) criteria for evaluating the quality of fixation. According to these criteria; less than 2 mm separation on joint regularity and angulations below 5 degrees on the sagittal and coronal planes are considered as excellent results; 2-5 mm separation or 5-10 degree angulations are considered as good results and separations above 5 mm or angulations over 10 degree angulations are considered as poor results. Radiological arthrosis was assessed, and regular joint or subchondral sclerosis was considered as stage 0, whereas the presence of osteophytes without joint narrowing was considered as stage 1, joint narrowing without the presence of osteophytes as stage 2, and complete narrowing of the joint or total deformation was classified as stage 3.

Figure 4. Fracture fixation under distraction with the external fixator. Anteroposterior image under flouroscopy

Statistical Analysis

The study is defined as level 4/case series, and power analysis or size sampling was not performed. Variables (Correction Quality, Radiological Arthrosis, Clinical Score and Fibula Fracture Type) were categorical data and sample size was less than 30. Normality tests were not performed because variables were categorical data. The relationship between the categorical variables was assessed with the chi-square test (non-parametric test). Results and statistical values were obtained using MedCalc (MedCalc Software Belgium 1993-2016).

RESULTS

Twelve patients (three female 25% and nine male 75%) with AO 43-C3 closed fracture were operated with the referred surgical technique. The average age was 50 (range: 36-62) years. Four patients had left (33.3%), eight patients had right (66.6%) pilon fractures. Six patients (50%) were admitted because of traffic accidents and six (50%) were admitted with injuries sustained from fall. Eight patients were diagnosed with fibula fracture (66.6%) (five comminuted 41.6%- three simple 25% fractures). The average time between trauma and surgery was 18 (range: 6-38) hours. The average follow-up period was 60 (range: 24-78) months (Table 1). No suture insufficiency was observed in the trauma area during the follow-up period. Soft tissue edema was recorded in all patients who were managed by elevation of the leg after surgery. No superficial or deep tissue infections were observed. The fixation quality according to Conroy et al. (11) was excellent in seven patients (58.3%) and the results in five patients (41.6%) were determined as a good. According to Teeny and Wiss (2) clinical scoring; the results obtained were rated excellent for four (33.3%) and good for eight (66.6%) patients. However, stage 1 arthrosis was observed on four patients (33.3%), stage 2 on six (50%) and stage 3 arthrosis was observed on two (16.6%) patients (Figures 5, 6).

The correction quality on four (33.3%) patients without fibula fracture was scored as excellent, the clinical scoring as excellent, and stage 1 arthrosis was observed on final follow-up. In three (25%) patients with simple fibula fracture, although the correction quality was scored as excellent, the clinical scores were rated good, and the development of stage 2 arthrosis was observed on final follow-up. In five (41.6%) patients with comminuted fibula fracture, the correction quality was scored as well as the clinical scores. On the follow-up radiographs, the existence of stage 2 arthrosis in three (25%) patients and stage 3 arthrosis in two (16.6) patients were diagnosed (Figure 7). Regarding the chi-square test, the relationship between correction quality and fibula fracture, the relationship between clinical score and fibula fracture, and the relationship between arthrosis and fibula fracture were significant ($p<0.05$). On the other hand, correction quality was not related to clinical score and arthrosis (Table 2).

DISCUSSION

Minimally invasive osteosynthesis offers various benefits. Minimal invasive osteosynthesis preserves the vascular circulation of the bone, leading to fewer refractures, non-unions, grafting requirements, and lower infection rates compared with conventional open surgery (12). Early-stage minimally invasive surgery was performed with the aim of avoiding soft tissue problems by preventing progressive edema of the soft tissues. In high-energy injuries, early bone fixation decreases postoperativeinfection and pain by increasing blood flow and venous return of the limb (13). In addition, with the application of percutaneous screws, indirect reduction maneuvers, and the application of low profile plates from small incisions, the skin problems have been significantly significantly (14). There were no soft tissue complications observed in patients during follow-up. No superficial or deep tissue infection was observed.

The reshaping of the articular surface with percutaneous screws is possible only by a good understanding of the bone stock of the pieces creating the joint surface and by determining the direction and distance of the separation. For this purpose, CT is recommended (6,9). CT findings not only provide detailed information about the fracture fragments but also offer insights into reduction and fixation options (15). The orientation and entry points of the lag screws to be applied on the basic joint parts were determined by working on CT sections. The fixation of the joint fragments was accomplished by sticking to the predicted screwing angles prior to surgery. Distraction to mobilize the joint

Figure 5. Case 1; preoperative AP-lateral radiographs (a), sagittal coronal CT scan (b), early postoperative (c) and 48th month radiographs are shown (d). Despite the development of stage 2 arthrosis, the result is one of the best with a 90 points Teeny & Wiss score

AP: Anterior posterior, CT: Computed tomography

Table 1. Demographic characteristics were listed on table

Sex	**3 female (25%)**	**9 male (75%)**	
Age	50	SD: 6.55	Range: 36-62
Side	4 left (33.3%)	8 right (66.6%)	
Trauma	6 MVA (50%)	6 fall from height (50%)	
Fibula fracture	4 non (33.3%)	3 simple (25%)	5 comminuted (41.6%)
Trauma-surgery	Mean: 18 hours	SD: 10.39	Range: 6-38 hours
Follow	Mean: 60 months	SD: 14.35	Range: 24-78 months

SD: Standard deviation

Table 2. Chi-square test results of the variables of the study. Existence and type of the fibula fracture was statistically significant regarding to correction quality, clinical score and arthrosis

	Fibula fracture	**Correction quality**
Correction quality	p=0.0025	-
Clinical score	p=0.0025	p=0.1473
Arthrosis	p=0.0061	p=0.0542

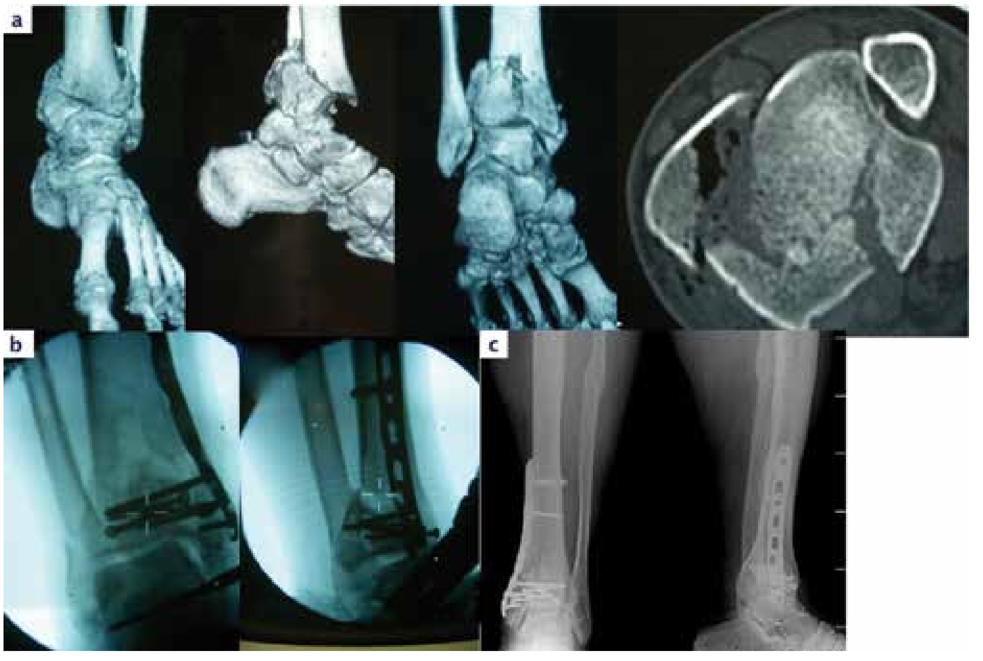

Figure 6. Case 2; preoperative 3D and axial CT scans (a), fluoroscopy images during the surgery (b) and 78th month follow-up radiographs are shown (c). Despite the development of stage 2 arthrosis, it is one of the excellent results with 97 points Teeny & Wiss score

CT: Computed tomography

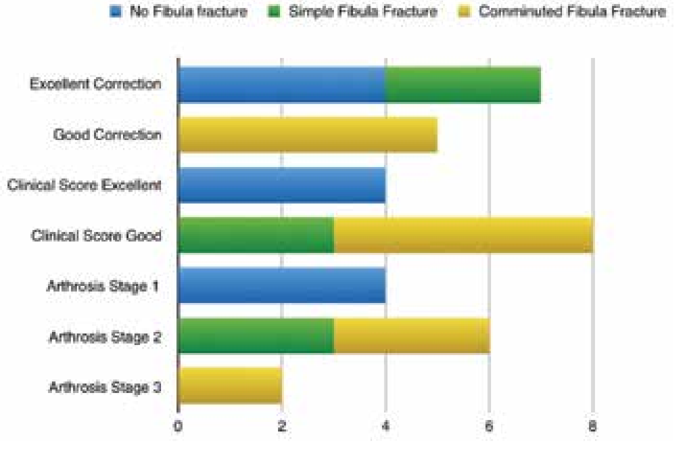

Figure 7. Distribution of the fixation quality, clinical score and radiological score according to fibular fracture

fragments was achieved by an external fixator. We observed that the medial implementation of the unilateral external fixator caused separation of the medial parts significantly more than the lateral parts. As prolonged use of an external fixator causes restriction of ankle motion, we avoided the use of a fixator during the postoperative stage (5).

For articular surface reduction, the goal is to achieve a step-off of less than 2 mm and an angulation of less than 5 degrees in both coronal and sagittal planes, as specified in the Conroy et al. (11) criteria. For reduction between the joint block and the metaphyseal-diaphyseal component, the goal is to achieve less than 5 degrees of varus, less than 10 degrees of valgus, and less than 10 degrees of sagittal plane deformity, as defined by Helfet et al. (16). The good correction was achieved in five (41.6%) patients according to Conroy et al. (11). These patients had comminuted fibula fractures and were subjected to a minimally invasive fibula fixation process. During the minimally invasive fibula surgery conducted on these cases, in which the length off the fibula was not fully restored, we observed anterior angulation off the posterior tibial joint fragment and stepping off the joint line due to relative shortening off the lateral column. The clinical scores of these patients were good. However, in the long-term radiological follow-up, we found stage 2 arthrosis in three (25%) patients and stage 3 arthrosis in two (16.6%).

Minimally invasive fibula fixation is recommended as long as the sagittal and coronal alignment of the fracture and the length of the fibula can be restored (1,8). Sagittal and coronal alignment can be achieved with fluoroscopic control. However, restoring the fibular length and its fixation with a minimally invasive procedure is not yet very clear. Evaluating the relationship between the tibial plafond and the subchondral ends of the lateral malleolus with the Mortise view or comparing the joint distance of the tibiotalar to talofibular joint are some of the methods used for fibular length control (13). However, it does not seems possible to make a healthy assessment of fibular length on pilon fractures where a fractured tibial plafond cannot be accepted as a landmark.

Assessing the fibular length by controlling the talocrural angle seems to be more useful. In any case, the anatomic alignment of the fibula fractures plays an important role in pilon surgery, and it is obvious that any alignment errors that might occur on fibula fixation will indirectly cause reduction errors of the tibial joint surface (1,3,17). Under these circumstances, we avoid insisting on minimally invasive fixation processes of fibula fractures when fibular length cannot be assessed radiologically.

According to Conroy et al. (11), the diagnostic quality scoring on seven (58.3%) patients was excellent, and the clinical scores for four of these patients were excellent whereas the scores for the remaining three (25%) patients were good. However, stage 1 arthrosis was present in four (33.3%) patients and stage 2 in three (25%) patients. These patients did not show any sign of alignment errors or stepping over 2 mm on the joint line that might have led to the development of arthrosis. The development of radiological arthrosis is associated with fracture fixation and the severity of the injury (18). In early open, staged open, and early minimally invasive series, the development of arthrosis in AO 43-C3 or Rudi type 3 cases, despite their excellent reduction quality, is higher than that in lower classified fractures (2,3,5,6). The post-traumatic occurrence of osteoarthritis on joints is directly related to the energy flow that the articular surface suffered at the time of the trauma and the shear forces that affectthe joint during the chronic phase. Non-anatomical correction of the articular surface causes chronic shear forces. This leads to an increase in the free oxygen radical volume, which in return leads to chondrocyte death (19). However, the same molecular changes and chondrocyte cell death also occur with the sudden energy charge that occurs at the same time as the trauma (20). Therefore, the possibility of developing arthrosis at an early stage increases with the higher energy level of the trauma (21).

High-energy injuries can lead to high-grade comminuted fractures, soft tissue damage that can create a coverage defect, and even vascular injuries, which delineate the boundaries of minimally invasive plate-screw osteosynthesis (22). Similarly, despite the encouraging results of minimally invasive plate osteosynthesis in pilon fractures, statistically significant differences can be observed in terms of functional scores and healing time when comparing AO 43-C fractures with AO 43-B and A fractures (23). High-grade comminuted fractures are challenging cases for the indirect closed reduction. Abdelgaid et al. (15) reported that in 7.69% of their case series, they could not achieve the closed reduction and resorted to open reduction.

There were no soft tissue complications observed in patients during follow-up. No superficial or deep tissue infection was observed. Although MIPO poses little or no damage to soft tissue, there are some challenges associated with the use of minimally invasive medial plate osteosynthesis in pilon fractures, including skin impingement, malunion, delayed union and intraoperative saphenous nerve, and vein injury (22-25).

CONCLUSION

We find the study to be meaningful on the basis that it covers the long-term follow-up results of a surgical method getting widespread in practice, which is performed only for AO 43-C3 fractures. We anticipate thatroviding anatomic reduction of the joint surface, early-stage minimally invasive plating of AO 43-C3 pilon fractures will help achieve satisfactory results and avoid soft tissue problems. The quality of the joint reduction and the effect of the energy load of the trauma bear great importance on the development of arthrosis. In addition, the importance of evaluating the joint fragments preoperatively and the need for a learning curve for correction techniques with the joystick method should be kept in mind.

Ethics

Ethics Committee Approval: The study was conducted with the permission of the Ümraniye Training and Research Hospital Clinical Research Ethics Committee (date: 15/05/2023, decision no: E-54 132726-000-215611251). The authors read the Helsinki Declaration and approved ethical obligations for the study.

Informed Consent: Informed consent was obtained from all patients.

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Authorship Contributions

Surgical and Medical Practices: T.B., Concept: T.B., Design: T.B., Data Collection or Processing: T.B., T.D., Analysis or Interpretation: T.B., T.D., Literature Search: T.B., T.D., Writing: T.B., T.D.

Conflict of Interest: No conflict of interest was declared by the authors.

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