Clinical and radiological assessment of the Polish modification of the Ilizarov external fixator for the treatment of intra-articular calcaneal fractures

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Abstract

Background. There is currently no established gold standard for the treatment of calcaneal fractures.

Objectives. To conduct a clinical and radiological evaluation of patients following intra-articular calcaneal fractures treated with the Polish modification of the Ilizarov method.

Materials and methods. This was a 2-center retrospective study. We evaluated 27 patients (2 women and 25 men) aged 28–73 years (mean age 50.5 years) after treatment of intra-articular calcaneal fractures with the Polish modification of the Ilizarov method. We assessed pain using a visual analogue scale (VAS), American Orthopedic Foot and Ankle Society (AOFAS) scores, patient satisfaction with treatment, use of analgesics, duration of Ilizarov treatment, length of hospital stay, duration of surgery, patient's declared willingness to choose the same treatment again, complications, degenerative changes, Böhler angle, inflection angle, and Gissane angle.

Results. The mean follow-up period was 3 years and 2 months. Following treatment, the mean VAS pain score was 2.3. Prior to surgery, all patients were taking analgesics in comparison with only 2 patients (7.4%) at long-term follow-up. The treatment was rated as satisfactory by 11 patients, with 16 patients rating it as highly satisfactory. The mean post-treatment AOFAS score was 76.6 points. The Ilizarov fixator was removed after a mean period of 88 days. The mean duration of hospital stay was 7.4 days. The mean duration of the procedure was 44 min. All patients would choose the same treatment again. Complications were observed in 5 patients. The long-term follow-up visit revealed degenerative changes in the talocalcaneal joint in 8 patients. The median Böhler angle was 5.5° preoperatively and 28.5° postoperatively, $p < 0.001$. The median preoperative inflection angle of 160° decreased to 145°, $p < 0.001$. The median preoperative Gissane's angle of 119° increased significantly to a median postoperative value of 143°, $p < 0.001$.

Conclusions. The patients achieved good clinical and radiological outcomes.

Key words: external fixator, Ilizarov method, radiological assessment, clinical assessment, calcaneal fractures

Background

Calcaneal fractures account for 1–2% of all fractures.[1–4] These fractures are predominantly intra-articular and displaced (75%).[1,4] Comminuted and intra-articular calcaneal fractures have been a serious orthopedic challenge for years.[1–13] There is no gold standard for the treatment of fractures of this type.[1–4,6,7,10–13]

The development of external fixation devices, particularly the Ilizarov method, enabled their use in the treatment of calcaneal fractures, even comminuted and/or intra-articular ones.[2–4,6–15] The use of the Ilizarov method in calcaneal fracture management has been reported to yield good outcomes, often even better than those achieved with internal fixation.[2,6] However, most authors who used the Ilizarov method did it with an open access approach to reducing the calcaneal fracture, which may have been responsible for complications in the form of infections, delayed wound healing, or skin and soft tissue necrosis.[2,3,6–10,12,13]

The Polish modification of the Ilizarov method enables closed reduction and fixation of the calcaneal bone fragments without an open access approach and allows stabilization of the foot with only 1 Kirschner wire.[4,15] There is only 1 study presenting the clinical and radiological results of closed reduction and Ilizarov fixation of calcaneal fractures with 1 Kirschner wire.[4] The authors of that paper evaluated 11 patients with calcaneal fractures treated with the Ilizarov method and analyzed selected clinical and radiological parameters (Rowe's score, Olerud–Molander Ankle score, Böhler angle, inflection angle).[4] Both the clinical and radiological parameters improved after treatment.[4] In another article, the authors assessed the balance and load distribution of the lower limbs after treatment of calcaneal fractures using the modified Ilizarov method.[15]

Those who have analyzed the treatment outcomes following calcaneal fracture management with the Ilizarov method usually assessed only selected clinical and radiological parameters.[2,3,6,9,13]

The reported peri-implant infection rates following calcaneal fracture treatment with the Ilizarov method were 16–33%.[2,3,6,10,12] There have also been reports of degenerative changes developing after this treatment; however, the authors did not assess the exact rates.[3,4]

We proposed the hypothesis that the Polish modification of the Ilizarov external fixator may help achieve good outcomes in the treatment of calcaneal fractures.

Objectives

The purpose of our study was to conduct a comprehensive clinical and radiological evaluation of patients following intra-articular calcaneal fractures treated with the Polish modification of the Ilizarov method.

Materials and methods

Study design

Our study was retrospective in nature. Thirty patients with intra-articular calcaneal fractures were treated with the Polish modification of the Ilizarov method (Fig. 1,2) in the years 2018–2021 in 2 academic level I trauma centers.

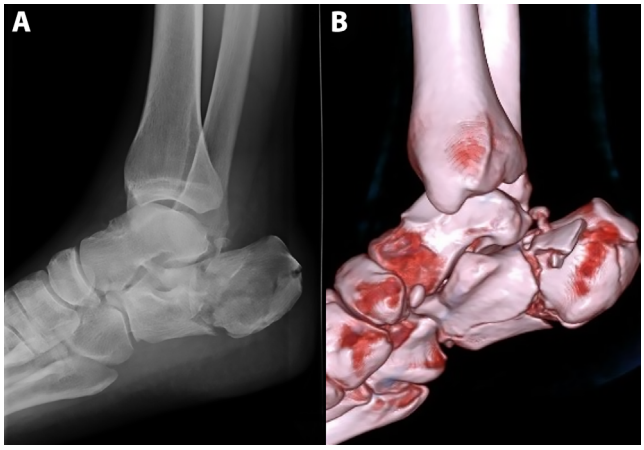

Fig. 1. The patient before treatment on (A) lateral X-ray and (B) computed tomography (CT) scan

Participants

The study inclusion criteria were a Sanders type II, III or IV calcaneal fracture treated with the Polish modification of the Ilizarov method, patient consent to participate in the study, complete medical and radiological records, a follow-up period of over 2 years, and no lower limb comorbidities. The exclusion criteria were a follow-up period under 2 years, incomplete medical records and incomplete radiological records. All patients were informed of the voluntary nature of their participation in this study. The study was approved by the Bioethics Committee of the University of Opole, Poland (protocol code UO/0023/KB/2023).

Interventions

All patients were diagnosed with a calcaneal fracture based on X-rays (anteroposterior and lateral views and the calcaneal axial view) and computed tomography (CT). The analyzed cases included 4 Sanders type II, 6 Sanders type III and 17 Sanders type IV calcaneal fractures. On arrival to the emergency room, all fractures were initially immobilized in a short leg cast. In the case of compound fractures (3 in the study population), the wounds were thoroughly rinsed, revised, cleaned, and sutured, and the limb was immobilized in a short leg cast on day 1. Patients with compound fractures received antibiotic therapy (600 mg clindamycin 3 times a day for 14 days, administered intravenously in the ward and orally for outpatient treatment). Fracture reduction and fixation with the Ilizarov method

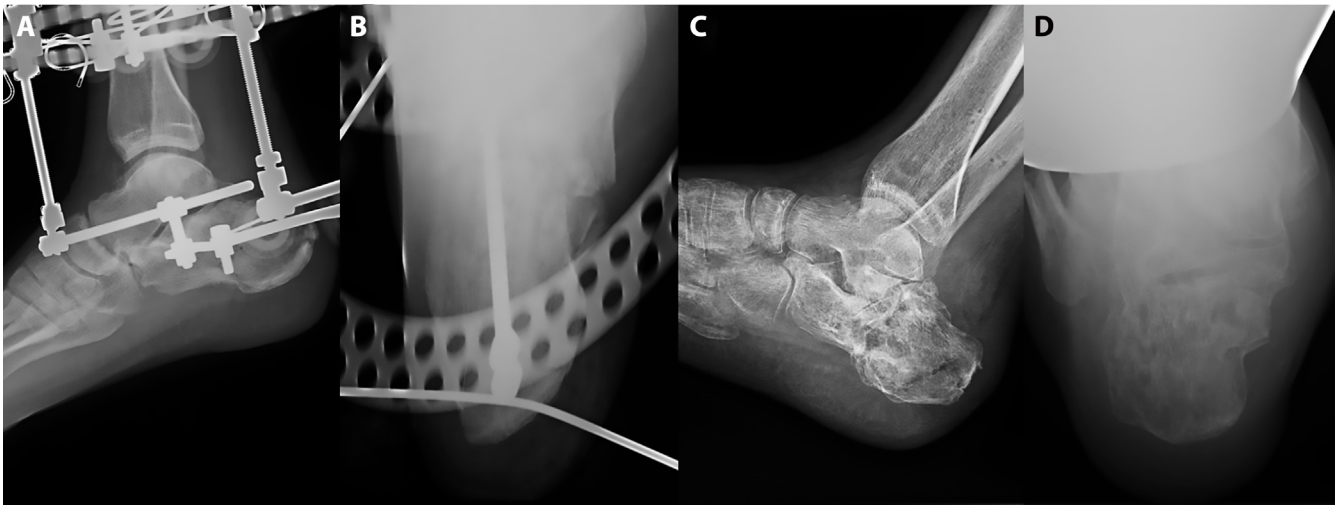

Fig. 2. The patient during (A, B), and after (C, D) treatment of an intra-articular calcaneal fracture with the Polish modification of the Ilizarov method

were conducted on days 3–5 after injury, depending on operating room and operator availability (all patients were operated on by the same orthopedic surgeon). Patients received perioperative antibiotic prophylaxis in the form of 1 dose of Biofazolin (1 g; BIOTON, Warsaw, Poland) administered intravenously.

The Polish modification of the Ilizarov external fixator was introduced for the treatment of calcaneal fractures in Wrocław, Poland, in the 1990s,[4,15] and personal communication: P. Koprowski and L. Morasiewicz. This modified external fixator comprised 2 rings, each fixed to the tibia and fibula with 2 or 3 Kirschner wires, and a semi-ring fixed with a single Kirschner wire inserted into the calcaneus (Fig. 3). The distal leg ring was attached to the calcaneal semi-ring with 2 connectors. The connectors were 2 threaded rods, attached perpendicularly to each other, enabling distraction and dorsal reposition of the calcaneal bone fragments (Fig. 3).

The procedure was performed in the supine position under spinal anesthesia. First, the 2 rings were attached with Kirschner wires to the tibia and fibula. Subsequently, a 2-mm Kirschner wire was inserted (under fluoroscopy) medially into the calcaneal tuberosity and into the most proximal and posterior bone fragment (Fig. 3). Then, a calcaneal semi-ring was attached to the Kirschner wire inserted into the calcaneus. The next step of the procedure involved joining the calcaneal semi-ring with the distal leg ring with 2 connectors (2 perpendicular threaded rods). Then, calcaneal fracture reduction was performed, under fluoroscopy, along the connectors between the calcaneal semi-ring and the distal leg ring (bone fragment distraction and dorsal repositioning were performed). The bone fragments were repositioned via closed reduction, under fluoroscopy, without opening the site surgically. This modified spatial arrangement of an Ilizarov external fixator and the effect of ligamentotaxis enabled an indirect correction of the calcaneal bone fragment's positioning. Thanks to an indirect alignment of the calcaneal bone fragments

Fig. 3. The Polish modification of the Ilizarov external fixator

in the sagittal plane, the modified arrangement of the fixator also enables the correction of the varus or valgus position of the calcaneal bone fragments (distraction or compression in the sagittal plane along 1 connector only).

The patients were allowed to walk with 2 elbow crutches and bear partial weight on the limb from the 1st postoperative day onward. A gradual increase in weight bearing was allowed as the pain subsided. If the wounds were healing well, the patient was discharged home on postoperative day 1. Follow-up radiographs were taken on the day of surgery, then 2 weeks and 6 weeks after surgery, and every 4 weeks thereafter until union. Bone union was determined based on radiological (callus, bone trabeculae crossing

the fracture line, or cortical continuity) and clinical evidence (no pain on physical examination, no pathological mobility of the bone fragments, painless weight bearing). If clinical and radiological evidence of union was present, the fixator was loosened at the connectors between the calcaneal semi-ring and the distal leg ring. The patient was allowed to walk, bearing full weight on the operated limb, and another follow-up radiograph was taken 7 days later. If there was no secondary displacement of the bone fragments and there was clinical and radiographic evidence of union, the Ilizarov external fixator was removed.

Variables

In this study, we assessed the following clinical and radiological parameters: pain severity using a visual analogue scale (VAS), American Orthopedic Foot and Ankle Society (AOFAS) scores, patient satisfaction with treatment, use of analgesics, period of time that the Ilizarov fixator was maintained on the lower limb, length of hospital stay, duration of surgery, patient's declared willingness to choose the same treatment again, complications, degenerative changes, Böhler angle, inflection angle, and Gissane's angle. The evaluated parameters were analyzed based on the available medical and radiological records and questionnaires completed by patients and doctors during a long-term follow-up visit.

Measurement

Pain severity was assessed with a 10-point VAS. Functional aspects were assessed with a 100-point AOFAS scale.[16] This tool helps evaluate ankle pain, range of motion, stability, and function.

The level of satisfaction with treatment was assessed on a 4-point scale: highly satisfied, satisfied, moderately satisfied, and dissatisfied.

We also assessed how many patients would choose the same treatment method again and how many patients were taking analgesic medications (tramadol, non-steroidal anti-inflammatory drugs (NSAIDs) and paracetamol) prior to surgery and at the time of their final long-term follow-up visit. The duration of Ilizarov treatment was expressed in days. The length of hospital stay was also measured in days. The duration of surgery was measured from the beginning to the end of the procedure and was expressed in minutes. The following complications were considered in our analysis: superficial pin-site infections, deep infections, skin and subcutaneous tissue necrosis, delayed wound healing, edema, necessity for reoperation, need for other procedures (arthrodesis, osteotomy or amputation), vascular injury, nerve injury, need for orthopedic footwear or shoe inserts following treatment, destabilization of the fixation, implant breakage, secondary displacement of the bone fragments, and nonunion. Possible degenerative changes were assessed based on radiographs taken at the long-term follow-up visit. The joints assessed for degenerative changes were the ankle joint, the talocalcaneal joint, the talonavicular joint, and the calcaneocuboid joint.[17] The Böhler angle, defined as the angle between a line joining the highest point of the anterior process of the calcaneus and the highest point of the posterior articular facet and a line joining the highest point of the posterior articular facet with the highest point of the calcaneal tuberosity, was assessed on lateral radiographs of the foot; normal values are 20–40°. The inflection angle, also assessed on lateral radiographs of the foot, was defined as the angle formed by the calcaneal tuberosity, the cuboid bone and the metatarsal heads (normal values: 145–150°). Gissane's angle, defined as the angle between the downward and upward slopes of the calcaneal superior surface, was also assessed on a lateral radiograph of the foot; normal values are 120–145°.

Bias

To avoid any source of bias, the measurements were recorded separately for every patient.

Study size

Application of the inclusion and exclusion criteria yielded 27 patients: 2 women and 25 men aged 28–73 years (mean age 50.5 years) included in our analysis.

Statistical analyses

The data were statistically analyzed using Statistica v. 13.1 (StatSoft Inc., Tulsa, USA). The Shapiro–Wilk test was used to check for normality of distribution. The Wilcoxon signed-rank test was used to compare quantitative variables. Bonferroni correction was used for multiple comparisons. The significance level was set at $p < 0.016$.

Results

Follow-up

The follow-up period ranged from 2 years to 5 years and 2 months (mean follow-up 3 years and 2 months).

Visual analogue scale

Following treatment, the mean VAS pain score was 2.3 (0–6). Prior to surgery, all patients were taking analgesics in comparison with only 2 patients (7.4%) at their long-term follow-up appointment. Eleven patients (40.7%) were satisfied with the treatment, and 16 patients (59.3%) were very satisfied.

American Orthopedic Foot and Ankle Society score

The mean post-treatment AOFAS score was 76.6 points (60–100). The Ilizarov fixator was removed after a mean period of 88 days (67–105 days) after surgery. The mean duration of hospital stay was 7.4 days (3–20 days). The mean duration of the procedure was 44 min (40–55 min). All patients would choose the same treatment again.

Complications

Complications were observed in 5 patients (18.5%). In all cases, these complications were superficial pin-site infections. In all patients, these infections were successfully treated with oral antibiotics and wound dressings. We observed no cases of deep tissue infections, skin or subcutaneous tissue necrosis, delayed wound healing, edema, necessity for reoperation, necessity for other procedures (arthrodesis, osteotomy or amputation), vascular injury, nerve injury, necessity for orthopedic footwear or shoe inserts following treatment, destabilization of the fixation, implant breakage, secondary displacement of the bone fragments, or nonunion.

The long-term follow-up visit revealed degenerative changes in the talocalcaneal joint in 8 patients (29.6%). There was no evidence of degenerative changes in the ankle, talonavicular or calcaneocuboid joints.

Böhler angle

The median Böhler angle was 5.5° preoperatively and 28.5° postoperatively. This difference was statistically significant (Z = –4.461, p < 0.001) (Table 1,2, Fig. 4).

Inflection angle

The median preoperative inflection angle of 160° decreased to 145° by the time of the long-term follow-up visit.

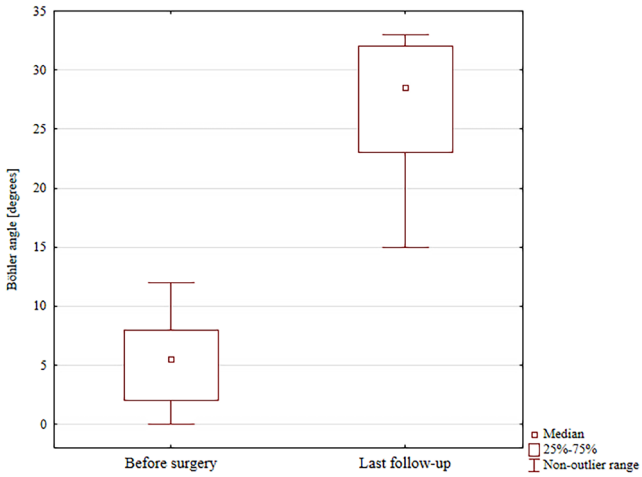

Fig. 4. Böhler angle values before and after surgery (Wilcoxon signed-rank test was used to determine significant differences)

Table 1. Detailed results before surgery and at the last follow-up

Analyzed variable		Value		p-value*
		before treatment	last follow-up	
Böhler angle [°]	Q1	2	23	<0.001
	median	5.5	28.5	
	Q3	8	32	
Gissane's angle [°]	Q1	113	137	<0.001
	median	119	143	
	Q3	131	157	
inflection angle [°]	Q1	150	140	<0.001
	median	160	145	
	Q3	170	150	

* Wilcoxon signed-rank test; Q1 – 1st quartile, Q3 – 3rd quartile

Table 2. The results of checking the normality of the data distribution (Shapiro–Wilk test) of the difference in values variables before and after surgery presented in Fig. 4–6.

Variables	W	p-value
Böhler angle [°]	0.83553	0.01
Gissane's angle [°]	0.85691	0.033
Inflection angle [°]	0.84071	0.014

W – the test value.

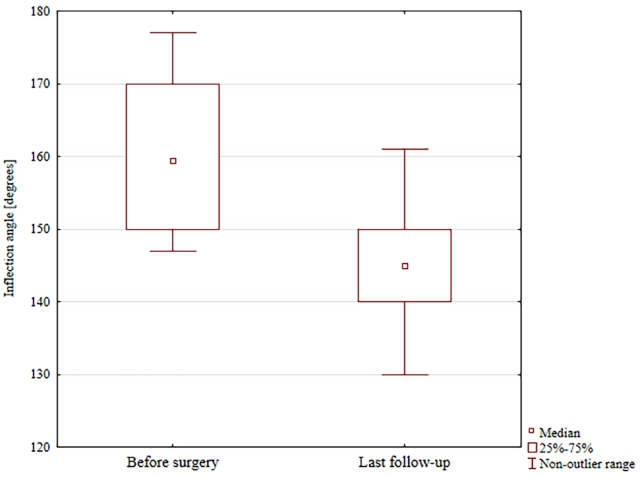

Fig. 5. Inflection angle before and after surgery (Wilcoxon signed-rank test was used to determine significant differences)

This difference was significant (Z = –3.9101, p < 0.001) (Table 1,2, Fig. 5).

Gissane's angle

The median preoperative Gissane's angle of 119° increased significantly to a mean postoperative value of 143° (Z = –4.384, p < 0.001) (Table 1,2, Fig. 6).

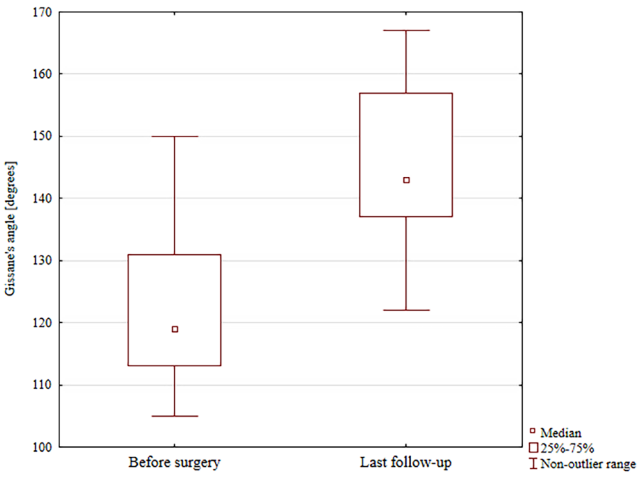

Fig. 6. Gissane's angle before and after surgery (Wilcoxon signed-rank test was used to determine significant differences)

Discussion

We conducted a detailed assessment of the clinical and radiological outcomes of using a modified Ilizarov fixator for the treatment of intra-articular calcaneal fractures. We observed good clinical outcomes and improved postoperative radiological parameters, such as the Böhler angle, the inflection angle and Gissane's angle, which supports our research hypothesis.

Most orthopedic surgeons use an open surgical approach for the treatment of intra-articular calcaneal fractures, which may be associated with high rates of complications, particularly superficial and deep tissue infections, delayed wound healing, and skin and subcutaneous tissue necrosis.[2–4,6–9,12–14,18–20] Using an open approach for the treatment of intra-articular calcaneal fractures is controversial due to high rates of limited range of motion, development of post-traumatic arthritis, infections, and delayed wound healing.[7] The Polish modification of the Ilizarov method for the treatment of intra-articular calcaneal fractures enables closed reduction, which is an advantage of this technique. Closed reduction lowers the risk of complications, shortens the duration of surgery and makes the procedure easier to perform.

Previous reports of calcaneal fracture management with the Ilizarov method mentioned the insertion of at least 3 Kirschner wires into the foot.[2,3,5–9,12–14,18–20] A higher number of implants inserted into the bones of the foot may further increase the risk of complications.[2,4] The modified Ilizarov method evaluated in our study requires only 1 Kirschner wire to be inserted into the calcaneus. The spatial configuration of Ilizarov external fixators presented by other authors for the treatment of calcaneal fractures is often complicated, bulky and burdensome for patients.[2,3,5–7,9] Usually, the Ilizarov external fixators seem to be arranged this way to improve bone fragment stability and achieve good fracture reduction.[2,3,5–7,9] Normal, anatomical repositioning of the bone fragments is believed to be the key factor for achieving good treatment outcomes in calcaneal fractures.[1,2,4–7] A normally shaped calcaneus determines the normal course of the pre-swing phase of gait.[4] Anatomical repositioning of the bone fragments and calcaneus reconstruction helps recreate normal anatomical relations of the foot structures and restores normal biomechanics.[1,2,4,6]

Our study shows that the evaluated modified Ilizarov external fixator, which requires only 1 Kirschner wire to be inserted into the calcaneus, is sufficient to achieve good clinical and radiological outcomes in the treatment of calcaneal fractures. This Polish modification of the Illizarov method ensures sufficient bone fragment stability to achieve union and correct bone fragment alignment and to restore calcaneal shape and structure. This is achieved through ligamentotaxis and the appropriate arrangement of the connectors joining the foot semi-ring and the distal leg ring (which allows for bone fragment distraction and dorsal repositioning). The corrected position and traction exerted by the most proximal and dorsal fragments of the calcaneus fixated using 1 Kirschner wire indirectly repositioned all the remaining bone fragments. The joint distraction, or arthrodiastasis, of the ankle joint and the talocalcaneal joint enabled by the Ilizarov fixator, may reduce the development of degenerative changes and reduce pain, which may result from arthrodiastasis-stimulated chondrocyte regeneration.[2,4,7]

There have been no studies assessing VAS pain scores following the treatment of calcaneal fractures using the Ilizarov method. Muir et al., who conducted a systematic review to analyze the treatment of calcaneal fractures with an external fixator, reported persistent pain in 36.7% of patients following treatment.[2] In our study, the mean post-treatment VAS pain intensity was rated at 2.3, which is a good outcome.

The systematic review by Muir et al. yielded a mean AOFAS score of 77.5.[2] In an 18-patient study conducted by McGarvey et al., the mean AOFAS score was 66.[3] Emara and Allam evaluated 12 patients after calcaneal fractures treated with the Ilizarov method and reported a mean AOFAS score of 88.2.[6]

Ali reported a mean AOFAS score of 68 in a group of 25 patients.[9] A group of 10 patients assessed by Li et al. had a mean AOFAS score of 80.[10] The 16 patients evaluated by Mauffrey et al. had a mean AOFAS score of 80.[13] In our study, the mean post-treatment AOFAS score was 76.6, which is consistent with the data found in the literature[2,3,6,9,10,13] and indicates good clinical and functional outcomes of managing calcaneal fractures with the Polish modification of the Ilizarov method.

There are no available literature reports on the level of patient satisfaction with calcaneal fracture treatment with the Ilizarov method. In our study, 40.7% of the patients were satisfied with their treatment, and the remaining 59.3% were very satisfied with their treatment. The Polish modification of the Ilizarov fixator requires

the insertion of a single Kirschner wire into the calcaneal bone and attaching it to the semi-ring, which leaves the midfoot and forefoot wire free. The Ilizarov external fixators used by other authors often take up more space, involve the entire foot, and require the insertion of at least 3 Kirschner wires into the foot.[2,3,5–9,12–14] The Polish modification to the fixator structure is the most advantageous spatial configuration in comparison with prior ones; it is also better tolerated by patients and less burdensome, and it produces higher levels of patient satisfaction with treatment.

There are no studies assessing the use of analgesics after Ilizarov treatment of calcaneal fractures. In our study, all patients had been taking analgesics before surgery, whereas by the time of their long-term follow-up visit, only 2 patients (7.4%) required analgesic treatment, indicating good long-term outcomes.

In the group of 33 patients evaluated by McGarvey et al., the Ilizarov external fixator was removed after a mean of 3 months after surgery.[3] In the group of 11 patients evaluated by Koprowski et al., the fixator was used for a mean of 3 months.[4] Emara and Allam, who evaluated 12 patients, removed the Ilizarov fixator after 3 months.[6] In our study, the Ilizarov fixator was removed after a mean of 88 days after surgery, which is consistent with the duration of Ilizarov treatment reported by other authors.[3,4,6]

In the study by Koprowski et al., the mean duration of hospital stay was 14.3 days in the younger age group and 7–10 days in the older age group of patients.[4] The patients in our study were hospitalized for a mean of 7.4 days, which is better than the duration of hospital stay reported by other authors.[4]

There have been no studies assessing the duration of surgery in the treatment of calcaneal fractures with the Ilizarov method. In our group of patients, the mean duration of surgery was 44 min, which is a good result that indicates a swift procedure. Nonetheless, some authors have described calcaneal fracture reduction and fixation with the Ilizarov method as a long and complex procedure.[2,3,5–7,9] The Polish modification of this method of calcaneal fracture treatment involves the insertion of a single implant into the foot, as opposed to the multiple implants typically required in other techniques. Furthermore, it does not necessitate an open surgical approach. This helps shorten the time of surgery and makes the method less complicated than what tends to be described in the literature.[2,3,5–7,9]

No other authors have evaluated patient willingness to choose the same method of treatment again after undergoing calcaneal fracture treatment with the Ilizarov method. All our patients declared their willingness to choose the same treatment method again if presented with a choice.

Muir et al., who conducted a systematic review of calcaneal fracture treatment with external fixators, reported persistent post-treatment pain in 36.7% of patients, limited mobility in 81% of patients, pin-site infection in 22.6% of patients, and the need to use orthopedic footwear or shoe inserts by 13.9% of patients after treatment.[2] In another study, McGarvey et al. reported limited range of motion in 80% of patients, with other post-treatment complications affecting 33.3% of patients; none of the patients required any additional procedures (arthrodesis, osteotomy or amputation).[3] Out of the 12 patients treated with the Ilizarov method and evaluated by Emara and Allan, 66.6% of the patients developed complications, which were pin-site infections in 16.6% of cases.[6] In the group of 10 patients assessed by Li et al., pin-site infections were reported in 20% of the patients.[10] Paley et al. reported pin-site infections in 14.3% out of the 7 evaluated patients, and the total proportion of patients who developed complications was 57.1%.[12] In our study, 5 patients (18.5%) developed complications; however, none of our patients required any additional procedures (arthrodesis, osteotomy or amputations). Superficial pin-site infections affected 18.5% of our patients, which is consistent with the data reported in the literature.[2,6,10,12] None of the patients in our study developed deep infections, skin or subcutaneous tissue necrosis, delayed wound healing, edema, vascular injury, nerve injury, or the need for orthopedic footwear or shoe inserts after treatment. The patients in our study underwent closed reduction, which may have lowered the complication rates in comparison with those reported by other authors.[2,3,6,10,12] The modified method of calcaneal fracture fixation used in our study allowed for walking and partial weight bearing on the operated limb as early as the 1st postoperative day. There were no cases of destabilization of the fixation, wire breakage, secondary displacement of the bone fragments, nonunion, or the necessity for reoperation. These results indicate good bone fragment stability. However, some authors, despite the use of at least 3 Kirschner wires for foot fixation, recommend bearing no weight on the operated foot for 3–10 weeks,[6,8,9,13] which may negatively affect treatment outcomes by restricting joint mobility, increasing the rates of edema, degenerative changes, and lowering the level of satisfaction with treatment.[2–4] A long period of reduced weight bearing on the operated limb may limit patient rehabilitation and lead to pain.[4]

Some authors have reported the development of degenerative changes after treatment of calcaneal fractures with the Ilizarov method; however, they did not specify the exact proportion of patients affected.[3,4] The possibly altered shape of the calcaneus leads to asymmetric load distribution through the ankle joint and the talocalcaneal joint and may result in the development of arthritis.[4] Evidence of osteoarthritis has been reported in 44–68% of patients after calcaneal fracture treatment.[2,9] Out of the 25 patients analyzed by Ali et al., 44% developed degenerative changes in the talocalcaneal joint and 24% in the calcaneocuboid joint.[9] In our study, 29.6% of the patients developed degenerative changes, within a mean period of 3 years and 2 months after treatment. In all cases, the degenerative

changes developed in the talocalcaneal joint. There was no evidence of degenerative changes in the ankle joint, talonavicular joint or calcaneocuboid joint. The Polish modification in the Ilizarov treatment of calcaneal fractures makes it possible to perform arthrodiastasis of the talocalcaneal and ankle joints,[4] which may limit the development of degenerative changes.[4,7] A long period of immobilization and reduced weight bearing in the treatment of calcaneal fractures is associated with an increased risk of complications, joint degeneration and stiffness, and poor treatment outcomes.[1,3] Our patients were allowed to bear weight on the operated limb very early, which may have limited the development of degenerative changes.

One study found that following open reduction and fixation with cannulated screws or a plate, the Böhler angle values improved by 16–30° in comparison with their preoperative values.[1] A systematic review of studies involving calcaneal fracture treatment with external fixators revealed the mean postoperative Böhler angle to be 24.8°.[2] In a group of 11 patients treated with the Polish modification of the Ilizarov method, the mean Böhler angle was 4° after injury and 27° after treatment.[4] In the evaluated group of 25 patients, Ali et al. observed an increase in the mean Böhler angle values from 11° before surgery to 24° after treatment.[9] The group of 10 patients assessed by Li et al. showed the mean Böhler angle value was 17.3° preoperatively and 25.9° postoperatively.[10] In 16 patients assessed by Mauffrey et al., the mean Böhler angle was 16° after the injury and 17° after treatment.[13] In our study, the median Böhler angle was 5.5° before surgery and increased significantly to reach 28.5° after surgery. The value of the Böhler angle achieved in our study is consistent with those reported by other authors.[1,2,4,9,10,13]

In the group of 11 patients assessed by Koprowski et al., the mean inflection angle was 154° prior to treatment and 147° after treatment.[4] We noted a median inflection angle of 160° before surgery, which decreased to 145° at long-term follow-up; these values are similar to those reported earlier.[4]

In the group of 10 patients evaluated by Li et al., the mean Gissane's angle was 100.5° before surgery and 109.5° after surgery.[10] Mauffrey et al., who evaluated 16 patients, reported a mean Gissane's angle of 115° before surgery and 106° after the operation.[13] In our study, the median preoperative Gissane's angle was 119°, and its value increased significantly to 143° after surgery.

The use of the Ilizarov method in the treatment of calcaneal fractures helps align the bone fragments during surgery and gradually correct their position afterwards in the case of failure to achieve normal alignment during surgery.[3,4,7] This helps achieve good radiological outcomes and reconstruction of the calcaneus. Reconstructing the normal shape of the calcaneus following a fracture helps restore normal load distribution in the foot and lowers the risk of degenerative changes.[4] The values of the evaluated radiological parameters in our group of patients were similar to those reported by other authors. The Polish modification of the Ilizarov method helps recreate the normal shape of the calcaneus and, depending on the nature of the fracture and the three-dimensional course of the fracture lines, its articular surfaces as well,[4] which is consistent with our findings. The radiographs obtained in our study showed the three-dimensional structure of the foot to be similar to normal.

The use of Ilizarov external fixators is particularly indicated in the case of calcaneal fracture with concomitant soft tissue injury, compound fractures, multiple trauma, and bilateral calcaneal fractures.[2,4,6,7]

The advantages of the Polish modification of the Ilizarov method in the management of intra-articular calcaneal fractures are the facts that it is easy to use, better tolerated by patients and minimally invasive, which minimizes soft tissue injury and reduces the risk of complications. The Polish modification of the Ilizarov method helps restore the shape and architecture of the calcaneus, which leads to normal load distribution in the foot and limits the development of post-traumatic arthritis.

Limitations

The limitations of our study include its retrospective character, which is due to the lack of possibility to assess clinical parameters prior to treatment in patients with calcaneal injury due to pain and pathological mobility of the injured calcaneus and the impossibility of predicting injury in advance. We would like to emphasize that other studies evaluating the treatment of calcaneal fractures were also retrospective in nature.[3–6,8–10,12–15,18–20] Another limitation of our study is the relatively low sample size, which was a result of several factors. One factor is the relative rarity of intra-articular calcaneal fractures; moreover, some patients lived far away from the study center and were unable to return for their final follow-up appointment. However, most other studies evaluating clinical and radiological parameters following calcaneal fractures also included similar, if not smaller, groups of patients.[3–6,8–10,12–15,18–20] Another limitation of our work is the lack of comparison of the results to patients with calcaneal fractures who underwent different treatment methods. Most available articles that describe the clinical or radiological results of the treatment of calcaneal fractures using the Ilizarov method[2–5,8–10,12–15,18–20] analyze the results of treatment only with the Ilizarov method, without a control group with different treatment methods. Another limitation of our study is the inclusion of patients with concomitant injuries. This was dictated by our eagerness to demonstrate the use of this modified Ilizarov method in the management of patients with calcaneal fractures and multiple other injuries and to increase the overall number of patients included in the study. Other authors also evaluated patients with calcaneal fractures, some of whom (30%) had concomitant musculoskeletal injuries.[4]

Another limitation of our work may be the disproportion in male/female distribution.

The strengths of our study are the uniform surgery protocol, the fact that the same orthopedic surgeon conducted all surgeries, the uniform rehabilitation protocol, and the fact that multiple clinical and radiographic parameters were assessed. We are currently planning a study in a larger patient population with a longer follow-up period. We also intend to prepare an article comparing the results of treating calcaneal fractures using the Polish modification of the Ilizarov method with those of a different treatment method, such as internal fixation.

Conclusions

The Polish modification of intra-articular calcaneal fracture treatment with the Ilizarov method helps achieve good stabilization of the bone fragments and restores the shape and architecture of the calcaneus.

The patients in our study exhibited lower rates of complications and degenerative changes than those reported by other authors who evaluated calcaneal fracture treatment with the Ilizarov method.

All patients in our study were satisfied or very satisfied with the treatment they received.

The patients achieved good clinical and radiological outcomes with the assessed Polish modification of the Ilizarov method for the management of intra-articular calcaneal fractures.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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