Minimally invasive surgery using an external circular fixator in the treatment of paralytic equinocavus foot deformity secondary to peripheral nerve lesion

Cirurgia minimamente invasiva empregando fixador externo circular no tratamento do pé equinocavo paralítico secundário à lesão nervosa periférica

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ABSTRACT

Objective: The objective of this study is to evaluate the efficacy of correction of rigid feet with severe equinocavus deformity secondary to peripheral nerve lesion. The treatment consists of minimally invasive surgery by gradual and progressive joint distension using a circular external fixator. **Methods:** In the period July 1993 to June 2010, seven patients were evaluated, all with complications of peripheral nerve lesion and with severe rigid equinocavus deformity of the foot and ankle. The main complaints were claudication, walking difficulty, and painful calluses under the metatarsal heads. Detailed clinical exam and simple radiographs, performed in the lateral view, with support, were compared before and after treatment to measure and grade the correction of deformity and improvement of symptoms. **Results:** Using clinical and radiographic criteria, we obtained a result that was considered good in six of the seven feet (86%); and regular in only one (14%). In the lateral radiographic evaluation of the foot and ankle, we found average correction of 9.5cm of the equine deformity and 1.0cm of the cavus deformity. There were no major complications during treatment. Complementary surgeries, including osteotomy of the heel (one foot), panarthrodesis (one foot), and arthrodesis of the hallux interphalangeal joint (one foot) were necessary to correct small residual deformities in three of the seven feet treated (43%). **Conclusion:** Minimally invasive surgery using a circular external fixator to correct severe and rigid equinocavus deformities of the

RESUMO

Objetivo: O objetivo deste estudo é avaliar a eficácia em tornar plantígrado, pés rígidos com prévia lesão nervosa periférica e que apresentam grave deformidade em equinocavo. O tratamento consistiu na cirurgia minimamente invasiva utilizando distensão articular gradual e progressiva por meio do fixador externo circular. **Métodos:** No período compreendido entre julho de 1993 e junho de 2010 foram avaliados sete pacientes, todos com sequela de lesão nervosa periférica e com grave deformidade rígida em equinocavo do pé e tornozelo. As queixas principais eram claudicação, dificuldade para marcha e calosidade plantar dolorosa sob a cabeça dos ossos metatarsais. Para mensurar e graduar a correção das deformidades e a melhora dos sintomas, foram realizados e comparados, antes e após o tratamento, um exame clínico detalhado e radiografias simples na projeção lateral com apoio. **Resultados:** Utilizando critérios clínicos e radiográficos, obtivemos resultado considerado bom em seis das sete extremidades (86%); e regular em apenas uma (14%). Na avaliação radiográfica lateral do pé e tornozelo, verificamos uma correção média de 9,5 centímetros do equino e de 1,0 centímetro do cavo. Não ocorreu nenhuma complicação maior durante o tratamento. Foram necessárias cirurgias complementares, incluindo osteotomia do calcâneo (uma extremidade), panartrodese (uma extremidade), ou artrodese interfalângica do hálux (uma extremidade), para corrigir pequenas deformidades residuais em três das sete extremidades

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foot and ankle is an efficient and relatively safe treatment alternative. In cases of symptomatic arthrodesis, this procedure significantly facilitates the execution of complementary arthrodesis, reducing the need for extensive bone resection and its potential complications.

Keywords:

Talipes cavus; Foot deformities; External fixators; Minimally invasive surgical procedures; Peripheral nerves

tratadas (43%). **Conclusão:** A cirurgia minimamente invasiva empregando fixador externo circular para corrigir deformidades graves e rígidas em equinocavo acometendo pé e tornozelo, constitui uma alternativa eficiente e relativamente segura de tratamento. Nos casos de artrose sintomática, esse procedimento facilita sobremaneira a execução de artrodese complementar, reduzindo a necessidade de ressecção óssea extensa e suas potenciais complicações.

Descritores:

Pé cavo; Deformidades do pé; Fixadores externos; Procedimentos cirúrgicos minimamente invasivos; Nervos periféricos

INTRODUCTION

Severe rigid equinocavus foot deformities can be seen in clinical practice in patients with a history of sequelae of severe traumatic injury involving the lower limbs(1-3), burns(4), compartment syndrome of the leg(1,2,5,6), peripheral nerve injury(7), or even central nervous system injury(8,9,10-13), among others. They are incapacitating injuries insofar as they: 1) prevent gait with plantigrade weight-bearing; 2) cause difficulty in independent locomotion and activities of daily living due to lameness and slowed gait; 3) hinder the use of conventional shoes; 4) may be the cause of chronic incapacitating pain mainly related to metatarsalgia arising from equinus weight bearing; 5) may lead to recurrent plantar ulceration in the forefoot when there is concomitant loss of protective sensation in the plantar region of the foot, significantly increasing the risk of infection and amputation; and 6) are associated with undesirable aesthetic appearance.

The treatment of severe rigid equinocavus foot deformities poses a considerable challenge to the orthopedic surgeon as an attempt to achieve acute correction in a single surgical procedure requires extensive dissection of the soft tissues, multiple osteotomies with resection of large bone wedges(14) and, potentially, complete resection of the talus or resection combined with the removal of other tarsal bones(14). Such procedures, when carried out during a single operation, jeopardize the foot's circulation and may entail amputation of the limb due to the high risk of vascular injury, extensive necrosis of the skin or deep secondary infection(4). This is especially true in the limbs where there are: 1) multiple scars due to previous surgery(5); 2) extensive scar tissue retraction with shortening and adhesion of the posteromedial neurovascular bundle of the ankle in those patients with severe trauma sequelae in the lower limb where there has been loss of soft tissue substance(2), compartment syndrome(1,2,5,6) or burns;(4) 3) paralytic diseases associated with loss of protective sensation in the feet(12-19); and 4) local circulatory disorder affecting the lower limb(1,20).

In addition to severe deformity, we must also take into account the poor quality of the skin, joint stiffness associated with arthrofibrosis, excessive shortening of the foot, loss of protective sensation of the feet, claw deformity in the toes and osteoarticular deformation in cases in which the problem started back in early childhood(1,3,5,8,15,18,21-31).

The aim of this study is to evaluate the efficacy of rendering rigid feet with previous peripheral nerve injury and severe equinocavus deformity plantigrade. The treatment consisted of minimally invasive surgery using percutaneous tenotomy of the Achilles and posterior tibial tendons, as well as release of the fascia and short plantar muscles, followed by the application of the modular circular external fixator to allow slow and gradual correction of the deformities and to produce foot and ankle alignment in the plantigrade position. Our hypothesis is that gradual and progressive joint distension allows the safe and satisfactory correction of these severe deformities.

METHODS

In the period between July 1993 and June 2010, 54 patients (60 feet) with severe rigid equinocavus deformities affecting the foot and ankle were operated on by the Foot and Ankle Surgery Group of the Department of Orthopedics and Traumatology of Santa Casa de São Paulo. Seven patients (13% of all operated cases) fulfilled the selection criteria of this study. Their deformities were present in patients referred to our institution due to neglected complications of irreversible peripheral nerve injury. None of these patients had used any appropriate preventative form of orthosis to try to avoid the progression of equinus, even after having been diagnosed with severe motor nerve damage of the affected limb.

We used plain radiography in the lateral projection with foot support, to define, measure and classify the severe equinocavus deformity affecting the foot and ankle. During the clinical examination, all the patients included in this study had markedly rigid limbs whose deformity could not be corrected with passive manipulation performed by the examiner; in addition, there was limited weight bearing on the forefoot during gait.

We defined severe equinus deformity when the distance measured between the inferior cortex of the posterior calcaneal region in relation to the ground line (calcaneus-ground distance) in the lateral radiograph was equal to or greater than four centimeters (Figure 1). We defined severe pes cavus deformity when the distance measured between a perpendicular line drawn from the inferior cortex of the navicular bone to a second line, joining the lower end of the calcaneal tuberosity to the inferior cortex of the head of the first metatarsal bone (called navicular height), measured three or more centimeters in the lateral radiograph with weight-bearing (Figure 1).

The surgical technique consisted of percutaneous tenotomy of the Achilles and posterior tibial tendons, and plantar fasciotomy with release of the bone origin of the adjacent muscles originating in the plantar medial calcaneal tuberosity. Plantar release was performed by making a curvilinear incision approximately three centimeters long alongside the origin of these structures in the plantar region of the heel (Figure 2).

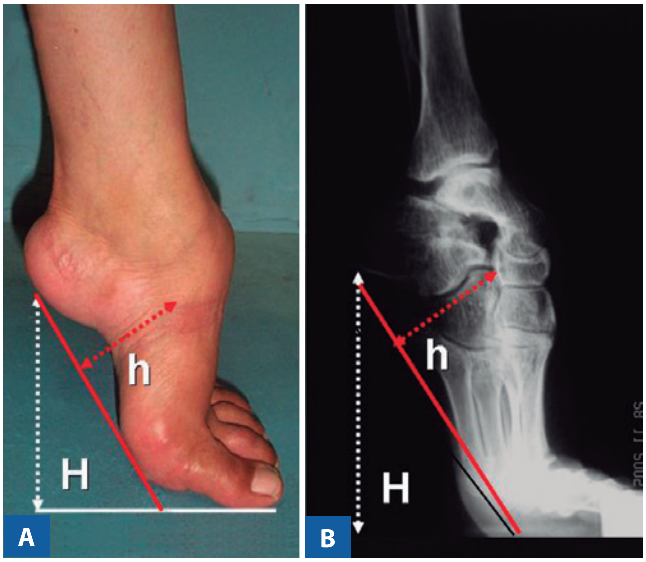

Figure 1 | Lateral photograph (A) and lateral radiograph of the left foot and ankle (B) of a patient with severe rigid equinocavus deformity of the foot and ankle secondary to peripheral nerve injury sequelae. Lines H and h demarcated in photographs A and B represent respectively the calcaneus-ground distance and the navicular height, measurements that are used to quantify the severity of the deformity.

Figure 2 | Transoperative photograph of the right foot showing the mini incisions used for the Achilles tenotomy (dotted circle) and plantar fasciotomy (continuous circle). When necessary we can use a third mini incision to tenotomize the posterior tibial nerve (clear arrow).

We then installed the modular circular external fixator using the assembly standardized by the Santa Casa de São Paulo Foot and Ankle Surgery Group[24-26]. This assembly consists of the creation of three interconnected, independent segments: 1) leg segment; 2) hindfoot segment; 3) forefoot segment. In the leg segment, we used two parallel rings, perpendicular to the tibial axis and separated from each other by a distance of approximately 10 centimeters. Each ring is attached to the tibia using two 1.5mm diameter Kirschner wires arranged crosswise. The distal ring is positioned approximately five centimeters proximal to the ankle joint interline. In the hindfoot segment, we used only a single semi-ring arranged parallel to the skin of the plantar margin of the heel surface. Two olive Kirschner wires, each 1.5 millimeters in diameter, are inserted across the body of the calcaneus, and a Schantz pin, 5 millimeters in diameter, is introduced along the axis of this bone. In the forefoot segment, we used two semi-rings, arranged parallel to each other and fixed perpendicular to the axis of the metatarsal bones. The fixation of the metatarsal bones is achieved using two olive Kirschner wires, with a diameter of 1.5 millimeters. Each of the wires essentially transfixes the first and fifth bones, in addition to the largest possible number of metatarsals, and is attached to its respective semiring (Figure 3). When performing the bone fixation of the forefoot it is always advisable to respect the conformation of the transverse metatarsal arch. The Kirschner wires attached to the tibia are tensioned up to 110kgf, while the wires attached to the calcaneus and metatarsals are tensioned up to 90kgf. The leg rings and the semi-rings of the hindfoot and forefoot are connected to each other by means of threaded bars, strategically positioned to permit progressive correction of deformities. Hindfoot equinus and varus will be corrected by connecting the leg assembly rings to the hindfoot assembly semi-ring; while adduction and cavus will be corrected by connecting the hindfoot assembly semi-ring to the forefoot assembly semi-rings (Figure 3).

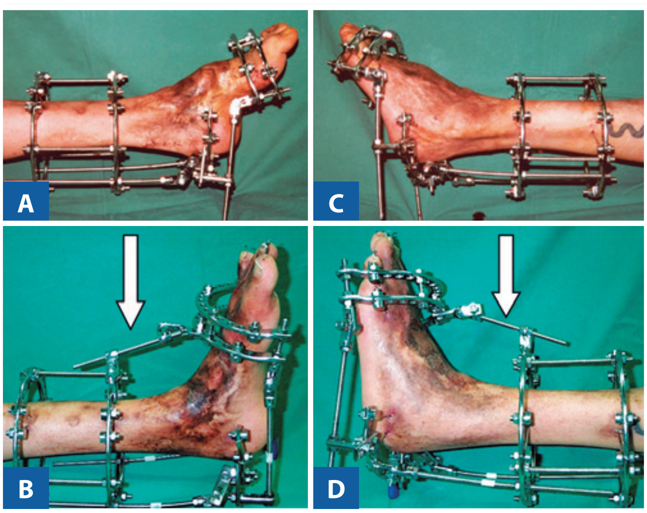

Figure 3 | Lateral photographic image of the left foot and ankle immediately after installation of the external circular fixator (A and C) and at the end of progressive correction of deformities over three months of treatment (B and D). Note the presence of the stabilizer connecting rod extending from the distal ring of the leg assembly to the proximal semi-ring of the forefoot assembly (white arrows in figures B and D).

In our series, progressive correction of deformities was started seven to ten days after surgery. The patients were kept in hospital so that the elongation of the connecting rods could be performed under medical supervision at least twice a day. Clinical parameters, such as pain, swelling or ischemia on the skin or fingers, were monitored throughout the deformity correction period. Upon admission, pain was controlled with oral medication (analgesic, anti-inflammatory and opiate derivatives) and patients underwent assisted motor physical therapy. After approximately eight weeks of treatment, we used clinical and radiographic criteria to judge whether complete correction of deformities had been achieved. We then indicated further surgery to correct possible residual claw deformity of the toes, using percutaneous tenotomy of the flexor tendons and temporary intramedullary fixation (four weeks) with 1.0mm diameter Kirschner wire (Figure 4).

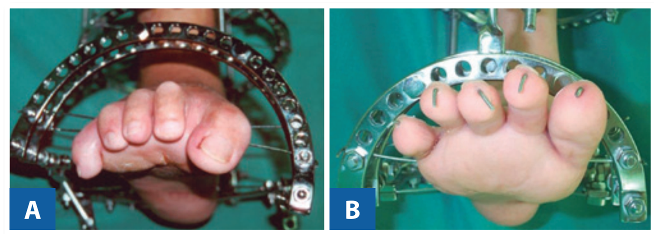

Figure 4 | Photograph showing the frontal aspect of the right foot showing evident claw deformity of the toes, accentuated during the process of correcting severe rigid equinocavus deformity using a circular external fixator (A). At the end of treatment, it is possible to align the toes by percutaneous tenotomy of the flexors and intramedullary internal fixation with metallic Kirschner wires (B).

At the same time, we made final adjustments to the external fixator to correct possible rotational deformities in the mid- and forefoot (pronation or supination). For this purpose, the patients were anesthetized and the lateral connecting bars attaching the semi-rings of the forefoot to the semi-ring of the hindfoot were temporarily loosened. We then performed manipulation and rotational alignment of the mid and forefoot, positioning the anterior portion of the foot in the slightly overcorrect position. Next, we reconnected the sidebars of the device and finally added an anterior connecting rod to fix the rings of the leg assembly to the semi-rings of the forefoot assembly. In this way, we were able to maintain the stability of the alignment achieved after complete correction of the deformities, closing the circuit of the leg-hindfoot-forefoot-leg connection (Figure 3). Patients were discharged for outpatient follow-up, with scheduling of weekly visits for four consecutive weeks, when the external fixator and toe Kirschner wires were removed with anesthetic sedation in an outpatient surgical procedure. The limb was immobilized with a cast boot and walking was encouraged in the subsequent six weeks. After removal of the plaster cast, the patients continued to use the polypropylene AFO orthosis for another six months.

In the period between March and May 2011, we summoned the seven selected patients for retrospective radiographic and clinical evaluation of results. A single independent examiner interviewed and examined the patients and radiographs. The criteria for inclusion in the study of the treatment of severe rigid foot and ankle equinocavus deformities were: 1) minimum follow-up time of 12 months; 2) skeletally mature patients to undergo surgery; 3) peripheral nerve injury sequelae deformity.

At the time of surgery, the six male patients and the only female patient included in this study, totaling seven treated limbs, had a mean age of 25 years (ranging from 21 to 33). In three patients, the lesion originally originated from the sciatic nerve, in two patients from the common fibular nerve and in another two from the popliteal nerve. The mean postoperative follow-up time was 62 months (ranging from 12 to 152) (Table 1).

To identify the frequency of complications present in our case series, we evaluated the occurrence of three clinical events frequently reported during the treatment of foot and ankle deformities with external fixator: 1) skin infection along the trajectory of the external fixator wires[15,24 -26]; 2) skin necrosis during the deformity correction period[24-26] and 3) incidence of claw toe deformity requiring surgical correction[24-26].

In order to classify the correction of equinocavus deformities and verify the effects of this treatment on the other foot and ankle joints, we took plain dorsoplantar and lateral radiographs of the foot and ankle with support. We performed a comparative evaluation of the differences found in the pre and postoperative radiographic images in relation to three items: 1) calcaneus-ground distance; 2) navicular height; 3) spontaneous bone ankylosis in the joints of the foot or ankle.

To consider whether or not the end result of the treatment was effective, we developed a binary method whose interpretation depended simply on the yes or no answer to four items. Three of these items evaluated the current clinical situation with the following questions: 1) is the foot plantigrade? 2) Does the heel rest fully on the ground?; 3) Has there been significant improvement in gait pattern in comparison to the preoperative period? Items 1 and 2 depended on subjective examination of the examiner, while item 3 depended on the patient's own opinion. In the fourth and last item of the evaluation, we used radiographic criteria comparing the pre and postoperative situations, measuring the calcaneus-ground distance and the navicular height on the lateral radiograph with weight-bearing by the foot and ankle. This criterion involved the radiographic analysis performed by the examining physician, who had to answer two objective questions: 1) in the postoperative evaluation, was the calcaneus-ground distance fully corrected and did it reach level zero?; 2) in the postoperative evaluation, did the navicular height in relation to the ground line decrease by at least 1.0 centimeter when compared to the preoperative condition?

At the end of the clinical and radiographic evaluation using the aforementioned method, the end result was considered good when the four questions were answered in the affirmative; fair when the answer was yes to three of the four questions; and unsatisfactory when the answer was yes to two or fewer items.

Regarding the final outcome of the treatment, we evaluated particularly those feet that required some type of supplementary surgery after the treatment with the external fixator. We took into account the answer to two different and decisive questions: 1) was it necessary to perform further surgery consisting of supplementary arthrodesis in situ or with minimal bone resection, indicated mainly because of

Table 1 | Distribution of patients with rigid equinocavus foot secondary to nerve injury who underwent surgical treatment with circular external fixator for correction of deformities

Case	Sex, age, side	Etiological diagnosis	Early complication	Additional surgery	Follow-up time	End result
1	M, 22, L	SNI	Claw, infection	N	12 months	GOOD - ankylosis
2	M, 24, L	SNI	Claw	Y (calcaneal osteotomy)	111 months	GOOD - ankylosis
3	M, 22, L	SNI	Claw, necro. and infect.	N	34 months	GOOD - ankylosis
4	F, 33, L	SNI	Claw	Y (panarthrodesis)	152 months	GOOD - arthrodesis
5	M, 21, L	SNI	Claw	Y (arthrodesis 1 IP)	18 months	GOOD - ankylosis
6	M, 23, L	PNI	Claw, infection	N	54 months	FR - ankylosis
7	M, 33, L	PNI	Claw	N	50 months	GOOD - ankylosis

Source: medical files of the Department of Orthopedics and Traumatology of Santa Casa SP.
M: male; F: female; B: bilateral; SNI: sciatic nerve injury; FNI: fibular nerve injury; PNI: popliteal nerve injury; claw: claw toe deformity; infection: local skin infection around the wires of the external fixator; necro: deep local cutaneous necrosis; N: no; Y: yes; 1 IP: interphalangeal joint; FR: fair.

the development of symptomatic arthrosis in the joints of one foot whose treatment with the fixator was able to satisfactorily correct the major deformities and achieve plantar weight-bearing during gait?; 2) was it necessary to perform further surgery consisting of supplementary modeling arthrodesis, indicated mainly because of the inability of the treatment with the external fixator to satisfactorily correct the deformities in such a way as to achieve plantar weight-bearing on the foot during gait?

RESULTS

Using the three binary criteria for clinical-functional evaluation and the only binary criterion of radiographic evaluation, we achieved a result considered good (plantigrade foot with heel resting fully on the ground, noticeable improvement in the gait pattern, calcaneus-ground distance on the lateral radiograph with weight-bearing equal to zero and decrease in the navicular height by at least 1.0cm) in six of the seven limbs (86%) (Table 1; Cases 1, 2, 3, 4, 5, and 7) (Figure 5).

The result was considered fair (three of the four binary evaluation criteria had a positive response) in one of the seven limbs (14%) (Table 1, Case 6, whose original injury affected the popliteal nerve). We did not obtain any result considered unsatisfactory, even in the presence of a severe problem in the skin of the leg and foot marked by extensive scar tissue retractions encompassing the posteromedial neurovascular bundle in five of the seven limbs (Table 1, Cases 1, 3, 4, 6 and 7).

In our case series, some common problems related to complications with the use of the external fixator were identified during treatment, with special emphasis on: skin infection along the trajectory of the wires in three limbs (43%); claw toe deformity that required surgical correction in all seven limbs (100%); and deep skin necrosis in a single limb (14%). Treatment of skin infections and of deep skin necrosis was performed with local care and did not interfere with the progress of the equinocavus deformity correction.

In comparatively analyzing the pre and postoperative lateral radiographs of the foot and ankle with support, we verified that the mean distance from the calcaneus to the ground was corrected from 10.0 centimeters in the preoperative period (ranging from 4.0 to 15.0) to 0.4 centimeters in the postoperative period (ranging from 0 to 4.0). Use of the external fixator to treat rigid equinocavus deformity enabled us to correct equinus, measured by calculating the calcaneus-ground distance, in the magnitude of 9.5 centimeters, on average. Regarding the navicular height, we observed that the mean of 4.6 centimeters in the preoperative period (ranging from 3.5 to 7.0) was corrected to a mean of 3.5 centimeters in the postoperative period (ranging from 0 to 5.0). The use of the external fixator enabled us to correct the cavus measured by calculating the navicular height, in the magnitude of 1.1 centimeters, on average (Figure 6).

Figure 5 | Comparative photographic and radiographic images of the left foot of patient 1 of our series whose lesion etiology was traumatic injury of the sciatic nerve. Note that in the front view of the foot (A) it is possible to identify marked claw toe deformity, whereas in the lateral view (B) there is a marked equinocavus deformity, also evident in the lateral radiographic image of the foot and ankle (E). Prior to surgery, the patient was only able to walk on tiptoe, but 12 months after surgery, the degree of correction achieved is clearly evident, and is visible both in the clinical images (B and D) and in the lateral radiographic image of the foot and ankle (F). At the end of the treatment, the patient was able to walk with plantigrade weight-bearing on the left foot (D).

We also verified the occurrence of spontaneous bone ankylosis in the postoperative lateral radiographs of the foot and ankle in practically all seven operated limbs. Six had spontaneous ankylosis of the fibrous or bone type. Of these, five were classified as a good result (Table 1, Cases 1, 2, 3, 5 and 7) while one was classified as a fair result (Table 1, Case 6). Supplementary additional surgery was performed in certain cases to correct residual deformities or to relieve

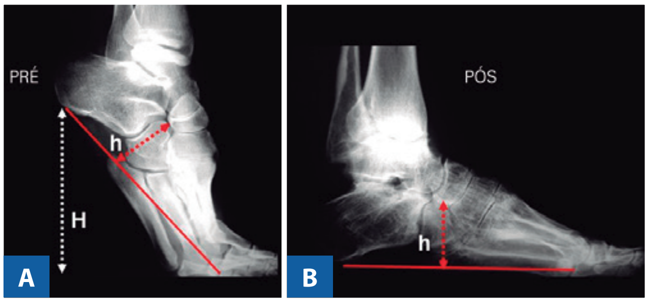

Figure 6 | Lateral radiographic images of the foot and ankle before (A) and after treatment of a severe rigid equinocavus deformity with modular circular external fixator (B). Note that line H, which represents the distance from the calcaneus to the ground, and is used to classify the equinus deformity correction, is evident in figure A (pretreatment image) and practically non-existent in figure B (post treatment image). Line h, which represents the navicular height and its variation in figures A and B, is used to classify the cavus correction after treatment.

painful symptoms resulting from arthrosis. Three of the seven limbs (43%), whose end result of severe rigid equinocavus deformity correction using the external fixator were considered good, required supplementary surgery. Calcaneal osteotomy was required to correct a residual varus deformity in a patient with sciatic nerve injury sequelae (Table 1, Case 2). Panarthrodesis, with minimal bone resection, was required in another patient with fibular nerve injury sequelae whose limb developed symptomatic arthrosis after having its main deformities corrected by treatment with the external circular fixator (Table 1, Case 4). Isolated arthrodesis of the interphalangeal joint of the hallux was required to correct rigid residual deformity in flexion in a patient with fibular nerve injury (Table 1, Case 5). The limb whose correction was considered fair belonged to a patient with popliteal nerve injury sequelae (Table 1; Case 6) and did not require supplementary surgery.

DISCUSSION

Conventional surgical techniques available for correction of rigid and severely deformed equinocavus feet and ankles can be applied in a single procedure and involve the abrupt correction of all components of the deformity.[4,21,22,29,31,32] In these circumstances, there is always a considerable risk to the circulation and viability of the limb during surgery.[4,21,22,29,31,32] This risk can be observed when we treat residual deformities resulting from unsuccessful attempts at modeling arthrodesis, performed previously in an attempt to surgically correct the severe equinocavus foot. We consider reoperation a constant concern since the presence of extensive adhesions and scar tissue retractions deeply attached to the posteromedial neurovascular bundle poses a high risk to local circulation and has considerable potential for complications[4,21,22,28,32]. In such situations, dissection for isolation and protection of the neurovascular bundle is often extremely difficult and laborious, and is not infrequently accompanied by laceration of these prime structures, jeopardizing the viability of the limb.[22,31] Moreover, to make abrupt correction of severe deformities possible during a single surgical procedure, it is often necessary to remove large bone wedges from the tarsus during osteotomies or modeling arthrodesis, which considerably increases the risk of bone and skin necrosis, as well as that of postoperative infection.[4,19,23,29] The result of the removal of bone wedges necessary to correct severe deformities is often excessive shortening of the foot or of the limb itself, which eventually causes a discrepancy in length in comparison to the contralateral limb[5,21,22,29,33,34].

A possible alternative for endeavoring to avoid the abovementioned problems is the use of progressive gradual correction using articular distension with the circular external fixator[5,10,21,22,24,26,35]. Due to its modular build, the circular external fixator allows gradual correction of deformities between the various segments of the foot and ankle, acting on three orthogonal planes: angulation, rotation and translation[22,23,28,35,36]. In this way, the surgeon is able to control the direction, speed and time needed to achieve complete correction of complex deformities[28,35]. According to previous studies, the control of these three variables reduces morbidity during treatment and minimizes complications when severe deformities are treated by this method[5,15,21,35]. In addition, the use of the external fixator makes it possible to correct severe equinocavus foot without the need for large incisions to access the joints that correspond to the vertices of the deformities. By means of this minimally invasive technique, it is possible to slowly and gradually traction, lengthen and angulate the connections between the various segments of the external fixator, enabling surgeons to align and correct the deformities established between the bones of the midfoot and the joints of the tarsus and ankle, according to the need of each particular case[24-26].

Several articles have been published, particularly in the last three decades, describing the use of the modular circular external fixator to correct severe rigid foot and ankle deformities in adults, emphasizing that it is a safe and effective method of treatment[1,2,15,22, 24-26, 28, 32]. The vast majority of these publications have the principle of osteogenic distention and histogenesis described by Ilizarov as a reference[37]. This principle states that both soft tissues and bone tissue are capable of growth after being submitted to controlled forces of gradual distension, performed slowly and progressively[37]. The actual traction provided during daily adjustments in the rods of the external fixator allows controlled accommodation to occur between the tarsal bones after their disimpaction[26]. Therefore, correction can be achieved without the need for any osteotomy, provided there is remaining joint space to allow adequate joint distension[24-26].

The standardized assembly of the modular circular external fixator for the foot and ankle facilitates the treatment of severe deformities by simplifying the installation of the device and reducing the number of variables during the process of making the adjustments needed for their correction.[24-26] The assembly used to treat the rigid and severely deformed limbs in this series of patients allows the connecting rods between the different segments encompassed in the assembly of the apparatus to be elongated independently. Thus, in this system composed of strategically placed hinges acting as a fulcrum, it is possible to correct the vast majority of structured multiplanar deformities that encompass the ankle, subtalar and midtarsal joints in a controlled but simultaneous manner[2,15,22,24-26,36]. Osteotomies are necessary in the bones of the leg or in the tarsus only in those limbs where previous spontaneous bone ankylosis has occurred or when residual equinocavus deformity persists after healing of arthrodeses performed previously that were fixed in an inadequate position[24,25].

In our case series, the traumatic peripheral nerve injury sequelae causing severe rigid equinocavus foot deformity was the main indication for treatment with the circular external fixator. Peripheral nerve injury in the lower limb often causes selective paralysis of muscle groups in the leg, generating imbalance between agonists and antagonists. This forms the basis for the development of deformities that are initially flexible and reducible, but which if neglected become rigid and permanently fixed due to capsuloligamentary retraction. Disorders or even loss of protective sensation in the foot are usually present in peripheral nerve injuries, which favors the appearance of chronic ulcers located in areas of friction with footwear or weight-bearing areas on the soles of the feet[2,9]. The decrease in the protective sensitivity of the limb entails a greater potential risk of complications during treatment with the external fixator, since the chance of developing infection in the skin around the wires is relatively higher due to the patient's lack of pain perception[2,24-26]. Partial loss of sensation in the affected limb is not infrequently combined with chronic pain and reflex sympathetic-dystrophy syndrome when there is incomplete nerve injury[7]. In our case series, even with all the difficulties predicted during the correction of severely deformed rigid feet associated with peripheral nerve damage, the frequency and severity of complications occurring during treatment were not higher than expected when compared to other series in which the same type of treatment was performed in patients whose limb had preserved sensitivity[15]. In fact, the occurrence of cutaneous complications around the fixator wires was quite common in our series, especially local infection. Nevertheless, it was possible to satisfactorily control this type of problem with local care alone, which did not prevent the continuity of treatment until complete correction of the deformities.

Severe problems in the skin of the leg and foot marked by extensive scar tissue retractions encompassing the posteromedial neurovascular bundle were present in five of the seven limbs treated in our series. As previously mentioned, the presence of scar tissue fibrosis near the anterior and posterior tibial arteries is known to greatly hinder any deep dissection to approach the foot and ankle joints, making conventional surgical procedures extremely risky, especially when it is necessary to bone wedges to correct severe deformities[7,31]. We believe that situations such as these are ideal for employing a minimally invasive and less aggressive technique for the soft tissues, using the circular external fixator to gradually and slowly correct rigid and fixed deformities. With daily adjustments to the device, it is possible to transform time into a controlled variable, allowing the local circulation of the limb to gradually adapt to the new position of the foot and ankle. In the case of conventional surgery, when attempting to abruptly correct all deformities necessary to render the foot plantigrade, it is not uncommon for the orthopedic surgeon to come across situations in which the circulation of the limb becomes insufficient. In our limited series of seven cases, we did not have any circulatory problems during treatment and we managed to achieve the planned correction in all limbs, even in the presence of serious problems in the cutaneous envelope and with partial loss of the protective sensitivity of the feet.

As an end result, we can consider that in general, minimally invasive surgery employing percutaneous tenotomy of the Achilles tendon and plantar fasciotomy, followed by the installation of the standardized modular circular external fixator assembly, allowed gradual and progressive joint distension to be performed until we achieved complete correction of the severe rigid equinocavus deformities in six of the seven operated limbs (86%). In a single limb (14%), the correction was partial and the end result was considered only fair.

The efficacy of the treatment using the modular circular external fixator could be observed when we analyzed the magnitude of the preoperative deformity at these limbs, especially when we take into account the severity of the equinus that was corrected. Using the lateral radiographic of the foot and ankle, we verified that the distance between the inferior surface of the calcaneus and the ground line, which in the preoperative period averaged 10 centimeters, dropped to just 0.4 centimeters at the end of the treatment. In the same radiographic projection, we were able to verify that the correction of cavus was also efficient, as the mean distance from the lower cortex of the navicular bone to the imaginary line joining the lower limb of the calcaneus tuberosity to the center of the head of the first metatarsal bone (called navicular height) went from four to three centimeters.

According to the criterion used to evaluate the result of this treatment method, we considered the method satisfactory when we achieved a stable, plantigrade foot in the final evaluation, able to support the heel and the full body weight on the ground. We also observed an improvement in gait pattern. The fact that the foot and ankle were completely rigid at the end of the treatment was not considered a limitation in the result, since the rigidity was present previously and the goal of this treatment method was not to restore mobility in the joints involved in the deformities. Some clinical studies, focused on comparing functional performance in patients undergoing surgery to salvage lower limbs with severe traumatic sequelae with other patients undergoing transtibial amputation using leg prosthesis, emphasize that the clinical and functional result is superior in amputees when we take functional performance, gait pattern and quality of life into account[20]. If we consider that the functional performance of a limb has circulatory and sensory deficit, and that the foot is completely rigid in this case, the indication of surgery to attempt to correct severe rigid deformities involving the foot and ankle is questionable. Attempting to preserve a severely deformed limb rather than amputating it may not make any sense in the present day, but some considerations must be taken into account, especially with regard to the lower energy expenditure required for walking, as well as the patient's own perception of the maintenance of their body as a whole. In third world countries with serious income distribution problems where resources are not always available for purchasing and maintaining prostheses, attempts to preserve a severely deformed limb whose foot and ankle are rigid, also need to be taken into consideration. Even with the rigid foot and ankle, the preserved lower limb may have its function compared to that of a long amputation stump, allowing independent gait without the need to use a prosthesis or crutch. When foot sensitivity is compromised, it is still possible to accommodate the foot in a protective shoe and to prevent the appearance of pressure ulcers.

In our series we did not consider the need for supplementary surgery, occasionally indicated to treat arthrosis or residual deformity, as a failure that would invalidate the proposed treatment method. When corrective tarsal osteotomy or arthrodesis was necessary, it was possible to use small incisions, without the need to remove large bone wedges to correct larger deformities. These supplementary surgeries can usually be considered less risky procedures with less chance of complications (skin necrosis, infection, additional neurovascular injury, etc.), since most deformities were corrected previously by treatment with the modular external fixator. In our series of seven cases, three supplementary surgeries were required. Two of these were small (a valgizing osteotomy of the calcaneus in patient 2, a hallux interphalangeal joint arthrodesis in patient 5) and only one of larger size (a panarthrodesis to treat symptomatic secondary arthrosis of the ankle and midfoot in patient 4). The three patients requiring supplementary surgery had no major complications and, at the end of the treatment, the result was considered good.

CONCLUSION

Minimally invasive surgery, employing the modular circular external fixator to gradually correct severe rigid equinocavus deformities that affect both the foot and the ankle, is an efficient and safe treatment alternative. Even when correction is not completely achieved, this method greatly facilitates the execution of supplementary arthrodesis, reducing the need for large incisions and dissections for extensive bone resection and its potential complications. This treatment proved to be an alternative to amputation of severely deformed limbs, allowing adequate alignment, stable plantigrade weight-bearing, and adequate functional capacity to allow independent gait. Its indication should be remembered, especially when we consider that in many third world countries access to prosthetics for transtibial amputation is also limited by the economic factor due to the poor distribution of income in the population.

REFERENCES

1. Beals TC. Applications of ring fixators in complex foot and ankle trauma. Orthop Clin North Am. 2001;32(1):205-14.
2. Ferreira RC, Sakata MA, Costa MT, Frizzo GG, Santin RA. Long-term results of salvage surgery in severely injured feet. Foot Ank Int. 2010; 31(2):113-23.
3. Shu H, Ma B, Kan S, Wang H, Shao H, Watson JT. Treatment of posttraumatic equinus deformity and concomitant soft tissue defects of the heel. J Trauma. 2011;71(6):1699-704.
4. Saghieh S, Bitar YE, Berjawi G, Harfouche B, Atiyeh B. Distraction histogenesis in ankle burn deformities. J Burn Care Res. 2011;32(1): 160-5.
5. Calhoun JH, Khazzam M, Manring MM, Kirienko, A. Fine wire fixation for foot deformities. Tech Foot Ank Surg. 2007;6(3):185-94.
6. Fulkerson E, Razi A, Tejwani N. Review: acute compartment syndrome of the foot. Foot Ank Int. 2003;24(2):180-7.
7. Thordarson DB, Shean JC. Nerve and tendon lacerations about the foot and ankle. J Am Acad Orthop Surg. 2005;13(3):186-96.
8. Mendicino RW, Kim C, Kabazie AJ, Catanzariti AR. Correction of severe foot and ankle contracture due to CRPS using external fixation and pain management: report of a pediatric case. J Foot Ankle Surg. 2008; 47(5):434-40.
9. Maranho DC, Volpon JB. Pé cavo adquirido na doença de Charcot-Marie-Tooth. Rev Bras Ortop. 2009;44(6):479-86.
10. Bishay SN. Single-event multilevel acute total correction of complex equinocavovarus deformity in skeletally mature patients with spastic cerebral palsy hemiparesis. J Foot Ankle Surg. 2013;52(4):481-5.
11. Kamath AF, Pandya NK, Namdari, S, Hosalkar, HS, Keenan MA. Surgical technique for the correction of adult spastic equinovarus foot. Tech Foot Ankle Surg. 2009;8(4):160-7.
12. Simis SD, Fuchs PMB. O tratamento do pé artrogripótico. Rev Bras Ortop. 2008;43(5):151-6.
13. Song HR, Myrboh V, Oh CW, Lee ST, Lee SH. Tibial lengthening and concomitant foot deformity correction in 14 patients with permanent deformity after poliomyelitis. Acta Orthop. 2005;76(2):261-9.
14. Dunn N. Stabilizing operation in the treatment of paralytic deformities of the foot. Proc R Soc Med. 1922;15(Surg Sect):15-22.
15. Emara K, El Moatasem EH, El Shazly O. Correction of complex equino cavo varus deformity in skeletally mature patients by Ilizarov external fixation versus staged external-internal fixation. Foot Ankle Surg. 2011;17(4):287-93.
16. Georgiev H, Georgiev GP. Talectomy for equinovarus deformity in family members with hereditary motor and sensory neuropathy type I. Case Rep Orthop. 2014;2014:643480.
17. Yalçin S, Kocaoglu B, Berker N, Erol B. Talectomy for the treatment of neglected pes equinovarus deformity in patients with neuromuscular involvement. Acta Orthop Traumatol Turc. 2005;39(4):316-21.
18. Hahn SB, Park HJ, Park HW, Kang HJ, Cho JH. Treatment of severe equinus deformity associated with extensive scarring of the leg. Clin Orthop Relat Res. 2001;(393):250-7.
19. Nomura I, Watanabe K, Matsubara H, Nishida H, Shirai T, Tsuchiya H. Correction of a severe poliomyelitic equinocavovarus foot using an adjustable external fixation frame. J Foot Ankle Surg. 2014;53(2):235-8.
20. Demiralp B, Ege T, Kose O, Yurttas Y, Basbozkurt M. Amputation versus functional reconstruction in the management of complex hind foot injuries caused by land-mine explosions: a long-term retrospective comparison. Eur J Orthop Surg Traumatol. 2014;24(4):621-6.
21. Bellamy JL, Holland CA, Hsiao M, Hsu JR. Staged correction of an equinovarus deformity due to pyoderma gangrenosum using a Taylor spatial frame and tibiotalar calcaneal fusion with an intramedullary device. Strategies Trauma Limb Reconstr. 2011;6(3):173-6.
22. Bor N, Rubin G, Rozen N. Ilizarov method for gradual deformity. Oper Tech Orthop. 2011;21:104-12.
23. El-Mowafi, El-Alfy, Refai M. Functional outcome of salvage of residual and recurrent deformities of clubfoot with Ilizarov technique. Foot Ankle Surg. 2009;15(1):3-6.
24. Ferreira RC, Costo MT, Frizzo GG, da Fonseca Filho FF. Correction of neglected clubfoot using the Ilizarov external fixator. Foot Ankle Int. 2006;27(4):266-73.
25. Ferreira RC, Costa MT, Frizzo GG, Santin RA. Correction of severe recurrent clubfoot using a simplified setting of the Ilizarov device. Foot Ankle Int. 2007;28(5):557-68.
26. Ferreira RC, Stefani KC, Fonseca FF, Santin RAL. Correção do pé torto congênito inveterado e recidivado pelo método de Ilizarov. Rev Bras Ortop. 1999;34(9/10):505-12.
27. Gibbons CT, Montgomery RJ. Management of foot and ankle conditions using Ilizarov technique. Curr Orthop. 2003;17(6):436-46.
28. Kocaoglu M, Eralp L, Atalar AC, Bilen FE. Correction of complex foot deformities using the Ilizarov external fixator. J Foot Ankle Surg. 2002; 41(1):30-9.
29. Paley D, Tetsworth KD. Deformity correction by the Ilizarov technique. In: Chapman MW. Operative Orthopaedics. 2ed. Philadelphia: Lippincott Willians & Wilkins; 1993. Cap. 61. p. 883-948.
30. Provenlegios S, Papavasiliou KA, Kyrkos JM, Kapetanos GA. The role of pantalar arthrodesis in the treatment of paralytic foot deformities. A long-term follow-up study. J Bone Joint Surg Am. 2009;91(3):575-83.
31. Shalaby H, Hefny H. Correction of complex foot deformities using the V-osteotomy and the Ilizarov technique. Strategies Trauma Limb Reconstr. 2007;2(1):21-30.
32. Zhong W, Lu S, Chai Y, Wen G, Wang C, Han P. One-stage reconstruction of complex lower extremity deformity combining Ilizarov external fixation and sural neurocutaneous flap. Ann Plast Surg. 2015;74(4):479-83.
33. Chen CM, Su AW, Chiu FY, Chen TH. A surgical protocol of ankle arthrodesis with combined Ilizarov's distraction-compression osteogenesis and locked nailing for osteomyelitis around the ankle joint. J Trauma. 2010;69(3):660-5.
34. Hansen ST Jr. Salvage or amputation after complex foot and ankle trauma. Orthop Clin North Am. 2001;32(1):181-6.
35. Butcher CC, Atkins RM. Principles of deformity correction. Current Orthopaedics. 2003;17(6):418-35.
36. Calif E, Stein H, Lerner A. The The Ilizarov external fixation frame in compression arthrodesis of large, weight bearing joints. Acta Orthop Belg. 2004;70(1):51-6.
37. Ilizarov GA, Shevtsov VI, Kuz'min NV. Method of treating talipes equinocavus. Ortop Travmatol Protez. 1983;(5):46-8.