Méd. Chir. Pied (2015) 31:23-31
DOI 10.1007/s10243-015-0398-y

ORIGINAL ARTICLE / *ARTICLE ORIGINAL*

Our Experience in the Surgical Treatment of Morton's Metatarsalgia with a Minimally Invasive Surgery Technique*

Notre expérience chirurgicale sur le névrome de Morton avec la technique mini-invasive

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Abstract The authors, while analyzing the nosologic framework of Civinini-Morton metatarsalgias, present their surgery case-study of 31 patients treated with a minimally invasive percutaneous technique. In particular, the neurolysis of the neuroma was performed through the percutaneous incision of the transverse intermetatarsal ligament (TIML) and through the distal metaphyseal osteotomy of the metatarsals contiguous to the involved intermetatarsal space, all of them being anatomical elements which identify the arch of the involved metatarsal canal. Of pivotal importance are the results of radiographic tests showing, in all the cases, a macroscopic reduction of the diameter of the nerve affected by nerve compression neuropathy. Furthermore, a remarkable percentage of the patients (70%) were exclusively treated with the osteotomy of the 3rd metatarsal. Such unusual procedure proved to further facilitate the postoperative course of the patient and the overcoming of some complications. The encouraging results obtained in this kind of surgical treatment place, in the authors' opinion, this technique among the most effective minimally invasive surgical treatments.

Keywords Morton's neuroma · Morton's metatarsalgia · Neurolysis of common plantar digital nerve · Surgical treatment of Morton's neuroma · Interdigital nerve compression syndrome · Distal metatarsal metaphyseal osteotomy (DMMO)

Résumé Après une classification de la maladie, suivant les hypothèses pathogéniques et biomécaniques les plus récentes, les auteurs décrivent leur expérience chirurgicale sur 31 patients opérés avec la technique percutanée mini-invasive. Onze patients en particulier ont été traités avec ostéotomie percutanée des deux têtes des métatarsiens contigus et la section du ligament intermétatarsien de l'espace affligé (le troisième ou le deuxième espace intermétatarsien), tandis que 20 autres patients ont été traités avec ostéotomie percutanée de la tête du troisième métatarsien et la section du ligament intermétatarsien de l'espace affligé (troisième ou deuxième espace intermétatarsien). Le résultat de la chirurgie, validé par Vas Test et la production instrumentale postopératoire (écho/IRM), est très encourageant, en particulier en ce qui concerne la population de patients traités par ostéotomie de la tête du troisième métatarsien.

Mots clés Chirurgie percutanée · Neurolyse de Morton · Névrome de Morton

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* This article was presented during the SFMCP congress, 12th December 2014.

Introduction

Civinini-Morton's metatarsalgia, most commonly known as "Morton's neuroma", is a painful condition of the forefoot that typically affects the 3rd or 2nd metatarsal space [1]. Several authors, over the years, have suggested different surgical techniques as possible solution to this pathology; we hereby present our results on a case-study of 31 patients treated with percutaneous osteotomy in the attempt to

decompress the vascular-nervous bundle and at the same time to obtain a correct distribution of weight on the forefoot.

Etiology

Since the first publication by Civinini (1835) [2,3], several authors have provided their scientific contribution in the attempt to identify the etiopathogenesis of this condition, which still nowadays remains not entirely clear. In 1876, Thomas G. Morton described this condition by publishing an article in the American Journal of the Medical Science and reporting the results of 12 cases of severe metatarsalgia affecting the 4th metatarsal head treated with the complete resection of the metatarsophalangeal articulation of the 4th toe and all the surrounding neurovascular structures [4]. Betts was the first to suggest that the neuroma or the inflamed nerves were the cause of pain due to microtraumatic injuries and recommended the surgical excision of the interdigital nerve, pointing out that it was thicker than the other interdigital nerves since it originated from the anastomosis of two nerves. He claimed that the interdigital nerve of the 3rd space was involved due to its connection to the flexor digitorum brevis muscle (anastomotic branch) and that during the dorsiflexion of the metatarsophalangeal articulation it was stretched by the transverse metatarsal ligament due to its stiffness and therefore the inability to adapt to weight bearing pressure while walking [5]. More recent studies, by contrast, have questioned this theory, verifying that the anastotomic branch was absent in 73% of the performed dissections [6], as suggested a few years earlier by Nissen [7] who proposed the vascular theory, according to which the neuroma resulted from a nerve ischemia. Mulder, by contrast, in 1951 described a thickened intermetatarsal bursa as a factor contributing to the development of the neuroma [8]. Also, Nissen and Shephard assumed that the thickened bursa contributed to the symptomatology in some patients [9,10] while Gilmour, who studied it in detail, noticed that the bursa was always thickened and that its changes inevitably caused a compression of the vascular-nervous bundle [11,12]. At present, like most of the authors [5,8,10–25], we think that Civinini-Morton metatarsalgia is a "Chronic Entrapment Neuropathy with Multifactorial Etiopathogenesis"; therefore, the term "Neuroma" proves to be inaccurate, because, despite the macroscopic aspect of the nerve in the involved portion, the lesions affect the endoneurium and the vessel walls with edema, hyalinization and sclerosis [15,18]. With the worsening of the sclerosis, endoneurial vessels, and endoneurium itself, the number of the myelinated nerve fibers decreases [19,20,22] and their sheaths become thinner giving rise to a thickening of perineurium and the sclerosis of epineurium with disordered proliferation of Schwann cells and fibroblasts with aspects of axonal demyelination. Such histological framework seems degenerative rather than proliferative and comparable to a perineural fibroma or elastofibroma, typical of an entrapment neuropathy [13,16,26]. Although often not evident, alterations of podalic support are always present. Tate and Rusin claim that in individuals with increased rearfoot varus, the tissues under the 4th metatarsal head and between the 3rd and the 4th metatarsals undergo friction for a longer time during gait. The anastomosis between medial and lateral plantar nerves might be subject to abnormal pressure responsible for the neuroma [23]; on the other hand, in our opinion, also in a pronated rearfoot (pronation syndrome, coxapedis dysplasia, pes cavus valgus, etc.) the absence of foot inversion during the transfer of weight bearing pressure from the forefoot doesn't allow the peroneus longus to stabilize the 1st ray to the ground causing an insufficiency of the 1st metatarsal, a transfer of the weight bearing pressure and an increase of the latter on the 2nd, 3rd and 4th metatarsal bones which—being unable to bear it and in conditions of great instability—would bring on a claw toe to compensate, increasing the dorsiflexion of the metatarsophalangeal articulations involved and causing the contraction of the flexor digitorum brevis muscle. This would further limit the adaptive ability of the nervous anastomosis since the effect of the tendon lever arm of the muscle would cause the adduction of the 4th metatarsal bone. It must be noticed that if the rearfoot everts with the pronation, the three central metatarsals evert as well, leading to a lateral displacement. Being the least movable of all, the 4th metatarsal represents the fulcrum around which the other metatarsals rotate during their movement in anterolateral direction, letting the transverse intermetatarsal ligament pinch the vascular-nervous bundle. This movement of the metatarsal heads is only possible when the foot is pronated actively at the level of the subtalar joint, and it is probably the most relevant mechanical factor leading to the development of Civinini-Morton metatarsalgia [14]. It is necessary to bear in mind the functional relationship between the astragalus foot and calcaneal foot and that the metatarsus, a "variable load structure" [15], becomes, in case of hyperpronation, "a constant load structure", representing a pressure block on intermetatarsal tissues. This biomechanical abnormality of the gait, if associated with other causes, such as certain sports as well as shoes with flat insoles (with little or no arch support) or with narrow toe box and semi-rigid outsole, contributes to Civinini-Morton syndrome. This pathogenetic interpretation leads us to take into consideration, while considering the surgical strategy of neurolysis, the distal metaphyseal osteotomy of the metatarsals involved in the entrapment syndrome, 1st of all of the 3rd metatarsal.

Clinical Presentation

Patients with Civinini-Morton metatarsalgia are commonly aged between 25 and 55 [25], predominantly of female gender probably due to the musculo-ligamentous laxity, which is more frequent in women, and for the restrictive footwear. Patients usually report spontaneous neuralgic pain, commonly located at the 3rd intermetatarsal space (less frequently the 2nd space and rarely the 4th) often radiating to 3rd and 4th toes or even to the calf. Reported pain is sudden and lancinating and usually arises during a long walk or after long hours standing with inadequate footwear. Pain is often relieved by taking shoes off and by massaging the affected area. In case of long-term affection, night pain can also be reported, probably due to the ischemia caused by the fibroneuroma and to the constant reduction of foot blood pressure while lying. On objective examination, the foot is normal, showing no cyanosis or edema, generally with no hyperkeratosis under the central metatarsal heads, particularly in the subjects with a relevant musculo-ligamentous laxity, but in our experience we could almost always appreciate asymptomatic osteophytes in the area of the 1st metatarsophalangeal articulation, confirming the insufficiency of the 1st metatarsal. Not rare is the presence of *digital diastema* between the affected toes, probably due to hypertrophied intermetatarsal bursae. The neurological signs, i.e., hypoesthesia (numbness) in the involved toes and/or hyperalgesia in the fingertips, are less specific and difficult to evidence during the anamnestic examination. Pain is reported with targeted palpation, dorsiflexion of the 3rd and 4th toes (Lasègue's sign) or lateral compression of the metatarsal heads (Mulder's maneuver) [8]. This maneuver produces a "click", a distinctive diagnostic sign of this condition [24], and sometimes gives the examiner the impression of squeezing snow in the hands. Radiographic examination (RX) must be always performed in common projections; it is not useful to diagnose or detect the fibrotic mass rather to exclude other pathologies and evaluate the possible bone (brachymetatarsia, cortical hypertrophy, hypermetropia) and joint modifications (arthritis, luxations, Freiberg disease, rheumatoid arthritis, etc.) which can better indicate foot movement mechanics in the patient. Ultrasound/elastosonographic examination (US), despite being an operator-dependent method, has proved to be certainly more effective over the years. It must be conducted using a transducer (7.5 Mhz or higher) for a dorsal and plantar scanning with dynamic maneuvers which cause the squeezing of the neuro-vascular bundle outside the intermetatarsal space. This maneuver allows the examiner to identify the neuro-vascular bundle, to evaluate its echogenicity and transverse diameter [17]. Elasonography, in experienced hands, represents, in our opinion, the most effective instrumental investigation, nowadays. Magnetic resonance imaging (MRI) can be used as well; in T1-weighted imaging a well-defined low-density mass can be observed for fibromas with a transverse diameter of at least 5 mm, while occasionally it can be noted in T2-weighted imaging, where the interdigital bursa can mislead the examiner [27]. Some authors recommend to conduct the MRI positioning with the patient in prone rather than supine position or in bipodal stance, as the transverse diameter would be more visible in these positions [28,29].

Conservative Treatment

Most patients affected by Civinini-Morton's metatarsalgia respond well to conservative treatment [24,25]. Initial treatment consists in changing gait mechanics, which is, with no doubts, the first cause of this pathology. Following an accurate clinical and instrumental examination, a customized plantar orthesis is manufactured, which can balance the pronosupination of the rearfoot and grant greater stability and a well-balanced transfer of forefoot load, keeping a metatarsal dilatation. In our clinical practice, after taking a two-dimensional imprint with a 2D scanner, we prefer to use a modular orthesis with a resin base of maximum 1 mm thickness, whereupon another well-shaped resin layer is welded, generally of 1.2–1.4 mm thickness, which allows a selective offloading of the metatarsal heads between which the fibroneuroma is located and a subcapitatum support under the insufficient metatarsal heads; upon the resins, there is then a latex foam retrocapitatum bar of 40–45 shore and with a maximum density of 200 Kg/m^3, hand-smoothed and stretched to follow the plantar arch. This bar is able to reduce the dorsiflexion of the central metatarsophalangeal articulations, which keeps the metatarsals splayed [30] and prevents rearfoot varus or rearfoot valgus; finally, the orthesis is coated with a semi-soft material. If the involved foot is pronated, we prefer to add a high-density heel pad of 3–5 mm thickness and 35 shore, and in case of musculo-ligamentous laxity also a varus wedge of 3 mm just behind the astragalus axis. The choice of materials (shore and density) and their thickness is directly proportional to the choice of the footwear which must be prescribed to the patient before the orthesis is manufactured: with semi-flexible sole, heels between 25 and 35 mm, and a wide toe box to allow the movement of toes. It is advisable to explain to the patient that the shoe must be of the right size and suitable for the positioning of the orthesis, which requires enough room in depth. A longer shoe would not bend at the level of metatarsal heads, but at the base of the toes. Orthesis manufacturing (design and production) takes several days; therefore, we prefer, after taking foot imprint, to apply taping to limit the movement of the subtalar joint in association with a padding with a 4–5 mm felt which can have the same effect as a retrocapitatum bar. As suggested by Reynolds [31], Mann [32] and other authors

[25,28], we also reckon that approximately 70–75% of the patients recover from metatarsalgia with plantar orthotic therapy. Generally, failure of this therapy or partial recovery is noticed in patients with a very limited functionality of the 1st metatarsophalangeal articulation (functional hallux limitus, hallux rigidus, hallux abducto valgus), but not in patients with a severe valgus deformity of the rearfoot or laxity. When recovery is not possible with plantar orthotic therapy, it is possible to start a pharmacological therapy with a high dose of vitamin B12 [25,28,30] to obtain an antineuritic effect and local infiltrations in the area of the affected nerve. Usually, 1 ml of corticoid (betamethasone) is injected, associated with 2 ml of aminoamide local anesthetic solution (1–2% mepivacaine) without epinephrine to reduce the hazard of tissue necrosis. Local infiltrations must be performed in the area of the affected metatarsophalangeal articulation [28], with a dorsal approach in order to be able to perceive the passage of the needle through the transverse intermetatarsal ligament as well as to avoid injecting the solution in the plantar adipose tissue. Often this maneuver triggers pain symptoms, which immediately disappear after the onset of action of the solution, a diagnosis confirmation for most authors.

Infiltrations can be performed upon the ligament, too, if a possible cause of pain is an intermetatarsal bursitis, which is hardly diagnosed. Infiltrations must be performed at intervals of 7–10 days and for a maximum number of 3. We personally prefer to avoid corticoids, both to prevent the inhibition of collagen synthesis (which would further weaken some overloaded structures such as the plantar plate) and for cutaneous dyschromias.

Surgical Treatment

Since a few years we have been dealing with minimally invasive percutaneous technique (MIS, minimally invasive surgery) on the foot.

For the entrapment syndrome of Morton's neuroma, we use more and more frequently the surgical technique introduced by Isham and De Prado in the late 90s [33].

The authors, in particular, report poor outcomes with just the percutaneous incision of the transverse intermetatarsal ligament, as suggested by Gauthier [34,35], or the endoscopic technique recommended by Barrett. They attribute the poorness of outcomes to the possibility that a hypertrophic scarring of transverse intermetatarsal ligament can further damage the nerve, and therefore associate a double percutaneous osteotomy of metatarsal heads with the incision of the ligament. Double osteotomy grants a "surplus space" for the neurolysis, thanks to the consequential dorsal translation of the involved metatarsal heads.

Eleven patients out of 31 have been treated with this kind of surgical technique.

On the remaining patients (20 out of 31), in addition to the incision of the TIML, we performed only an osteotomy of the 3rd metatarsal.

Actually, the osteotomy of the 3rd metatarsal alone allowed us to obtain the same surgical outcomes with fewer complications and a faster healing period.

The single osteotomy of the 3rd metatarsal allows us, in our opinion, to obtain an effective neurolysis of both the 2nd and the 3rd intermetatarsal spaces and to grant the forefoot a more effective postoperative accommodation, in line with what was stated in the description on the pathogenesis of this neuropathy.

Surgery Technique

For this procedure an electric drill Osada 30W (Fig. 1) was used, equipped with a micromotor with 2.7/1 reduction speed handpiece (SH29).

Fig. 1 Micromotor Osada 30W

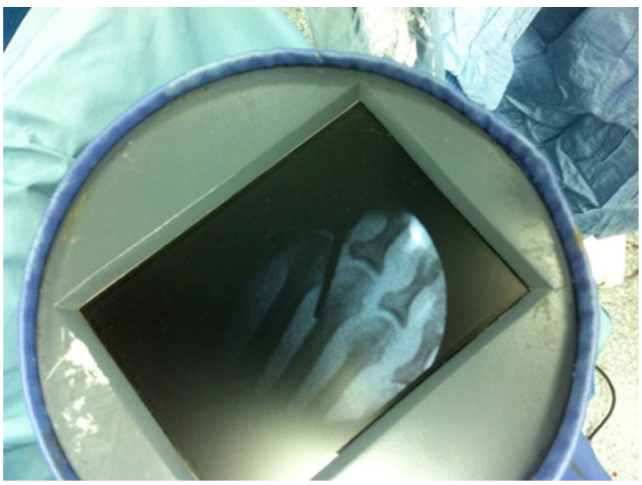


Fig. 2 X- ray fluoroscopy mini-amplifier

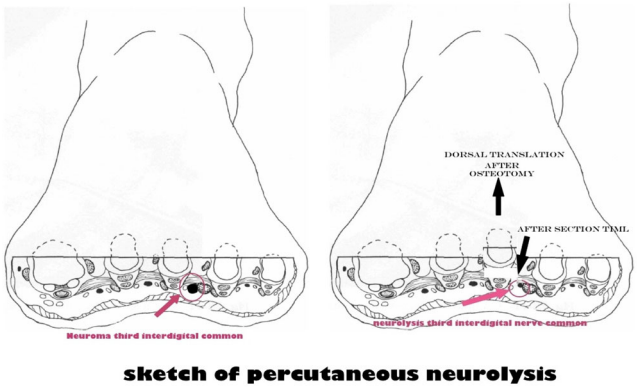


Fig. 3 Metatarsal head osteotomy and dorsal displacement

GROUP A

patients receiving double osteotomy (2/3 or 3/4 metatarsus)	2 space	3 space	bilateral 2 e 3 space
11	1	8	2

Fig. 4 Group A reported in 11 patients treated with double osteotomies of the metatarsal heads contiguous

GROUP B

patients receiving single osteotomy 3 metatarsus	2 space	3 space	bilateral 2 e 3 space
20	2	18	—

Fig. 5 Group B reported in 20 patients treated with only the head of the third metatarsal osteotomy

This equipment allowed us to operate on the metatarsal heads at lower speed (about 5000–6000/min).

A 2.0 × 12 mm steel Isham burr was used, too.

With the help of a brightness mini-amplifier (Fig. 2), we identified the dorsal injection access point and the web space to be treated.

Fig. 6 X-ray examination of the metatarsal osteotomized at 40 and 70 days after surgery neurolisys

With an infiltration of carbocaine in the spaces around the metatarsal head to be osteotomized, we obtained an effective local anesthesia.

Through a mini-incision of about 1 cm, we introduced a bone rasp and identified the transverse intermetatarsal ligament, as well as the *metatarsal head* to be osteotomized.

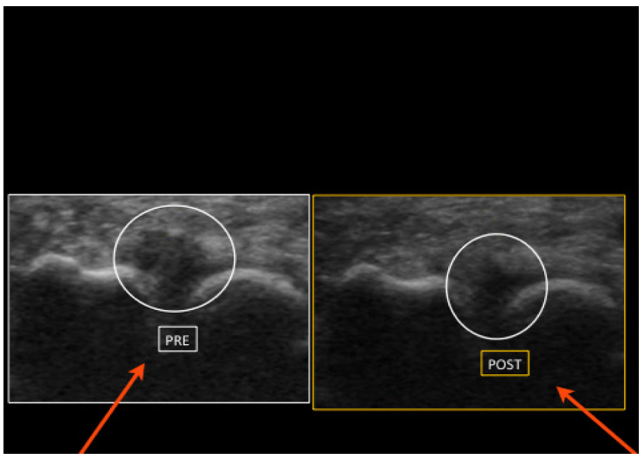


Fig. 7 Ultrasound examination of the pre- and postoperative neuroma after six months

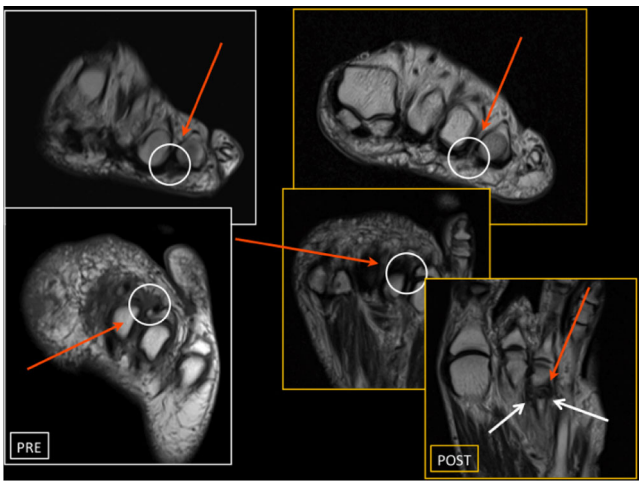


Fig. 8 IRM with disappearance of neuroma to six months after surgery neurolysis

A n.64 beaver blade was used to incise along the bone of the involved metatarsal, until we found the resistance of the intermetatarsal ligament, which was properly sectioned.

Once Isham burr had been inserted, preceded by a local irrigation with saline, the metatarsal osteotomy was performed (Fig. 3) with a disto-proximal angle of 45°, as close as possible to the metaphyseal region of the metatarsal head.

The final outcome was confirmed on palpation and by the radiographic instrumental comparison. With one single Vicryl ultrarapid 3/0 suturing stitch, we assured the closure of skin flaps. Finally, with the plastering of the corresponding toe in plantar flexion, we obtained a further dorsalization of the metatarsal head.

Results

Between June 2012 and July 2014, we surgically treated 31 cases of neuroma: 25 women and 6 men. In all the cases, a conservative management with ortheses and/or local cortisone infiltrations was formally used.

All the patients were assessed with a general clinical examination of the foot, an instrumental examination (US vs. MRI) and finally with an FFI (foot function index) questionnaire.

In 11 cases (Group A) the surgical treatment applied was a double percutaneous osteotomy of metatarsal heads and a percutaneous incision of the adjacent transverse intermetatarsal ligament (Fig. 4).

Among these 11 cases, 2 were affected by bilateral neuroma (2nd and 3rd intermetatarsal spaces), while among the remaining 9 patients, in 8 cases the neuroma affected the 3rd space and in 1 case the 2nd space. In 8 cases we met an excellent patient satisfaction.

In 2 cases we met a delayed osteotomy consolidation (turned into a *franca pseudarthrosis* in 1 year), however registering a good patients satisfaction despite the delayed consolidation.

Finally, we also had a case report of non-responder.

Later, we subjected the other 20 patients to the single osteotomy of the 3rd metatarsal, preceded by the percutaneous incision of the intermetatarsal ligament of the interested space. In 18 cases the neuroma affected the 3rd intermetatarsal space and in 2 cases the 2nd space.

In this second group (Group B) of 20 patients, we registered an excellent patient satisfaction (Fig. 5) and one single case of non-responder patient. In this second group, we met neither delayed consolidation nor pseudarthrosis. In one single case, with persistent symptoms, we performed (after 5 months) a local cortisone infiltration which proved to be effective (medical check after about 13 months).

All the patients were allowed to immediate ambulation with a rigid-sole postoperative shoe and to ambulation without ortheses after 3 weeks.

All the patients showed a moderate postoperative edema, which sensibly reduced in 40 days from the surgical treatment.

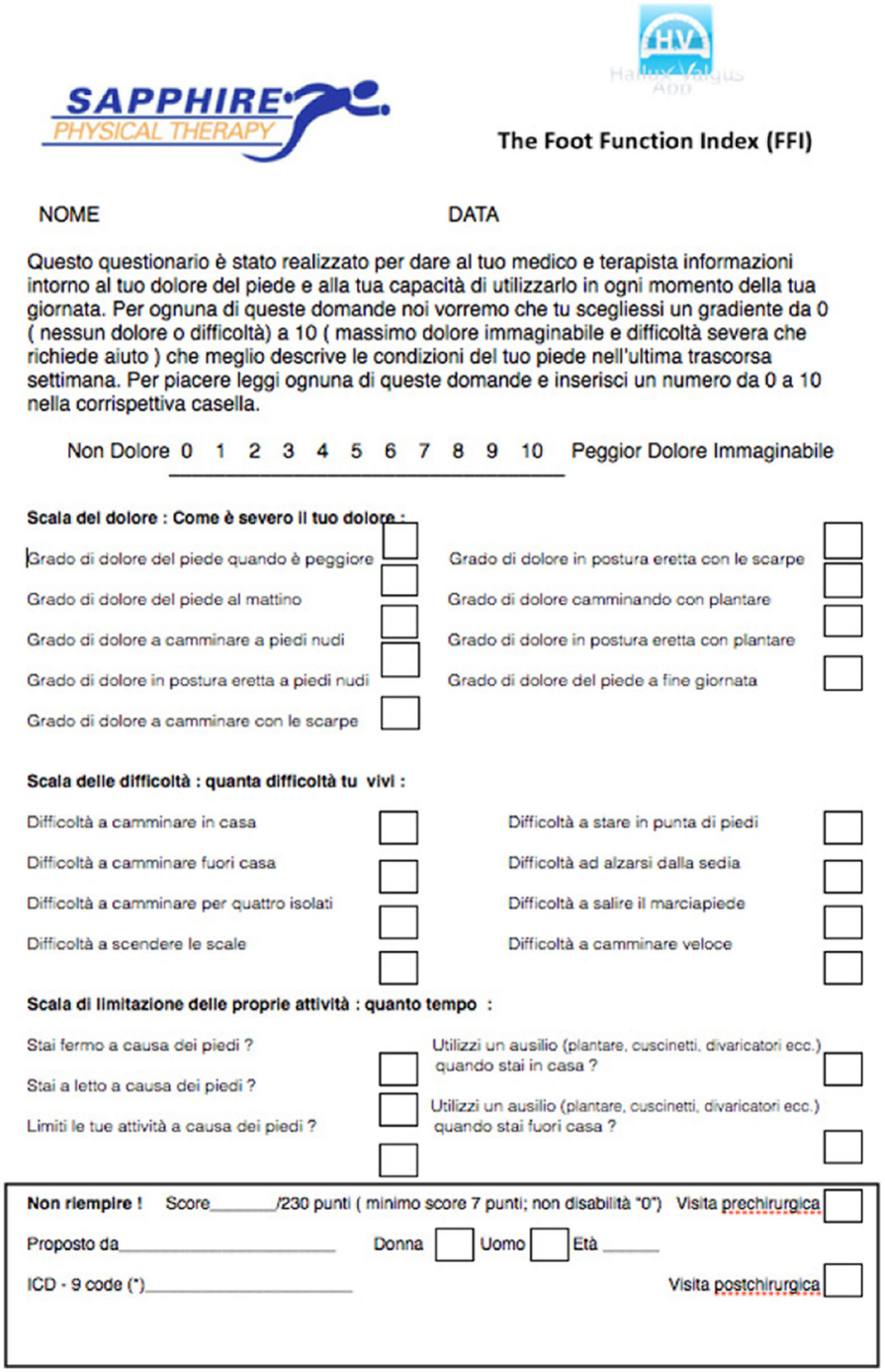
Forty days after surgical treatment, patients were subjected to a radiographic check and after 3 months to an US/MRI check.

With the radiographic check, we monitored the process of bone consolidation in order to check the postoperative recovery timing (Fig. 6).

US and/or MRI test showed in all the cases (also in the 2 non-responder cases) a reduction in the diameter of the neuroma, and in some cases its complete disappearance (Figs 7, 8).

All the patients were assessed with an FFI (foot functional index) questionnaire, submitted before surgical treatment and 3 months after surgical treatment (Fig. 9).

This questionnaire allowed us to evaluate, besides pain symptoms (VAS test), the disability of this condition, too.



SAPPHIRE PHYSICAL THERAPY

The Foot Function Index (FFI)

NOME DATA

Questo questionario è stato realizzato per dare al tuo medico e terapista informazioni intorno al tuo dolore del piede e alla tua capacità di utilizzarlo in ogni momento della tua giornata. Per ognuna di queste domande noi vorremo che tu scegliessi un gradiente da 0 (nessun dolore o difficoltà) a 10 (massimo dolore immaginabile e difficoltà severa che richiede aiuto) che meglio descrive le condizioni del tuo piede nell'ultima trascorsa settimana. Per piacere leggi ognuna di queste domande e inserisci un numero da 0 a 10 nella corrispettiva casella.

Non Dolore 0 1 2 3 4 5 6 7 8 9 10 Peggior Dolore Immaginabile

Scala del dolore : Come è severo il tuo dolore :

- Grado di dolore del piede quando è peggiore
- Grado di dolore del piede al mattino
- Grado di dolore a camminare a piedi nudi
- Grado di dolore in postura eretta a piedi nudi
- Grado di dolore a camminare con le scarpe
- Grado di dolore in postura eretta con le scarpe
- Grado di dolore camminando con plantare
- Grado di dolore in postura eretta con plantare
- Grado di dolore del piede a fine giornata

Scala delle difficoltà : quanta difficoltà tu vivi :

- Difficoltà a camminare in casa
- Difficoltà a camminare fuori casa
- Difficoltà a camminare per quattro isolati
- Difficoltà a scendere le scale
- Difficoltà a stare in punta di piedi
- Difficoltà ad alzarsi dalla sedia
- Difficoltà a salire il marciapiede
- Difficoltà a camminare veloce

Scala di limitazione delle proprie attività : quanto tempo :

- Stai fermo a causa dei piedi ?
- Stai a letto a causa dei piedi ?
- Limiti le tue attività a causa dei piedi ?
- Utilizzi un ausilio (plantare, cuscinetti, divaricatori ecc.) quando stai in casa ?
- Utilizzi un ausilio (plantare, cuscinetti, divaricatori ecc.) quando stai fuori casa ?

Non riempire ! Score_____/230 punti (minimo score 7 punti; non disabilità "0") Visita prechirurgica

Proposto da_____ Donna Uomo Età _____

ICD - 9 code (*)_____ Visita postchirurgica

Fig. 9 Foot function index score

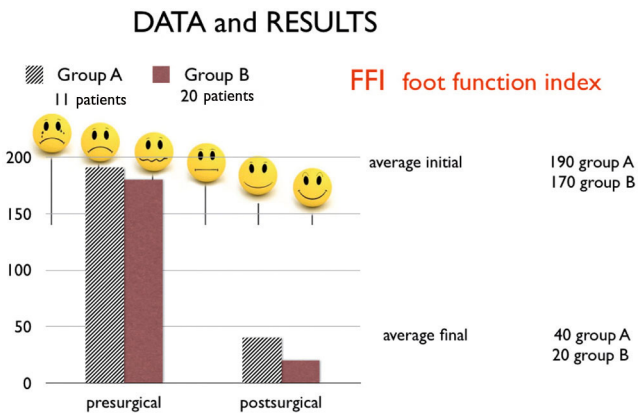


Fig. 10 Decrease disability and pain of the foot after neurolisys

In corroboration of the efficient surgical treatment and of the following clinical check, the postoperative outcomes of FFI questionnaire show and confirm a positive improvement in the functional recovery of the forefoot both for the disappearance of pain and of disability (Fig. 10).

Conclusions

The outcomes of our surgical case-study seem very encouraging.

We have further improved some disadvantages of the De Prado-Isham technique (transfer-metatarsalgia and pseudarthrosis), with the single osteotomy of the 3rd metatarsal.

The rationale of our surgical choice lies in the question we asked ourselves while studying the possible pathogenesis of Morton's neuroma. Particular attention was paid to the effectiveness of conservative treatment with a biomechanical orthesis, reported by a great number of patients who weren't subjected to surgery.

The single osteotomy of the 3rd metatarsal gave us the possibility to restore surgically a more physiological anterior transverse arch and a better balance of forefoot loads.

Surgical Outcomes

The two groups of patients were affected, excluding one single case (double osteotomy), by no transfer metatarsalgia.

The case of transfer metatarsalgia was successfully treated with a subsequent additional osteotomy of the 2nd metatarsal.

In the cases of symptoms persistence, excluding the non-responder, we met a total resolution of symptoms even at 6 months from surgery.

The two non-responder patients (1 case in the double osteotomy and 1 in the single osteotomy of the 3rd metatarsal) refused open surgery and, in our opinion, the negative outcome is due to the degenerative nerve structure, which didn't respond to a single neurolysis.

Besides the temporary postoperative edema, we met no particular complications, such as operative wound dehiscence, algodystrophies, recurrence of neuroma, and infections.

In our opinion, on the basis of the achieved outcomes, such surgery technique can be a valid alternative to traditional open surgery techniques and be considered as a proper minimally invasive technique (alcoholization, radiofrequency, endoscopy, etc.).

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