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CLINICAL ARTICLE

Choosing the target wisely: partial tibial nerve transfer to extensor digitorum motor branches with simultaneous posterior tibial tendon transfer. Could this be a way to improve functional outcome and gait biomechanics?

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OBJECTIVE The objective of this study was clinical assessment of the reduction of pathological motor phenomena with the recovery of long toe extensors, and evaluation of functional outcome with simultaneous nerve and tendon transfer in cases of common peroneal nerve (CPN) injuries.

METHODS Seven male patients (mean age 26.4 years) received a partial tibial nerve transfer to the extensor hallucis longus muscle (MEHL) and extensor digitorum longus muscle (MEDL) motor branches, after a mean of 2.7 months following a traction-type injury to the CPN. Tibialis posterior muscle (MTP) tendon transfer through the interosseous route was performed on the same day. The follow-up period included a clinical neurological examination, a modified Stanmore System questionnaire (MSSQ), electromyographic examination of the interference pattern, and a video-based analysis of the gait biomechanics in the 3rd and 12th months. Video analysis of the gait investigated the presence or reduction of "stair-climbing maneuver" (SCM), foot slap (FS), and foot stability during the gait cycle.

RESULTS The average range of active dorsiflexion in the 3rd month was 0.85°. SCM accompanied walking in 6 patients (86%). FS accompanied walking in 3 patients (43%) and 3 patients (43%) avoided FS by planting the entire foot on the ground. All patients required orthopedic support (shoe inserts) to compensate for mediolateral foot instability. The average MSSQ score was 80.4 points. The average duration for the effective recovery of function (≥ 4 points on the Medical Research Council grading system) of long toe extensors was 11.2 months. The average range of active dorsiflexion in the 12th month increased to 4.4°. A reduction of FS was observed in 5 patients (71%). Excessive foot eversion was reduced in 4 patients (57%). Another 3 patients (43%) required no specific orthopedic shoe inserts. Reduction of pathological motor phenomena with recovery of the long toe extensors resulted in an increase of functional outcome. The average MSSQ score after 12 months was 92.4 points.

CONCLUSIONS Partial tibial nerve transfer to the motor branches of the extensor hallucis longus and the long toe extensors along with the simultaneous tibialis posterior tendon transfer produce the reduction of FS and bring mediolateral stability to the foot, i.e., improved gait biomechanics. The reduction of pathological motor phenomena at the time of recovery of the long toe extensors is reflected in an increase in patients' functional perception of the injured lower extremity during daily walking.

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KEYWORDS tibial nerve; common peroneal nerve; nerve transfer; tendon transfer; electroneuromyography; gait biomechanics; peripheral nerve

Movement complexity, controlled by the common peroneal nerve (CPN), plays a significant role in the biomechanics (and muscle coordination) of human walking. CPN injury can occur as a result of an accident, a gunshot wound, a sciatic nerve tumor, radiculopathy, hip and knee replacement surgery, etc.[3,6,10,19] Injury to the CPN results in antigravity weakness to the tibialis anterior muscle, toe extensors, and peroneal muscles. Consequently, this leads to loss of ankle dorsiflexion, toe extension, ankle eversion, and pronation.[19]

ABBREVIATIONS CPN = common peroneal nerve; EMG = electromyography; FFL = forefoot loading; FS = foot slap; HO = heel off; HS = heel strike; MEDL = extensor digitorum longus muscle; MEHL = extensor hallucis longus muscle; MRC = Medical Research Council; MSSQ = modified Stanmore System questionnaire; MTP = tibialis posterior muscle; SCM = stair-climbing maneuver; TB = terminal branch; TO = toe off.

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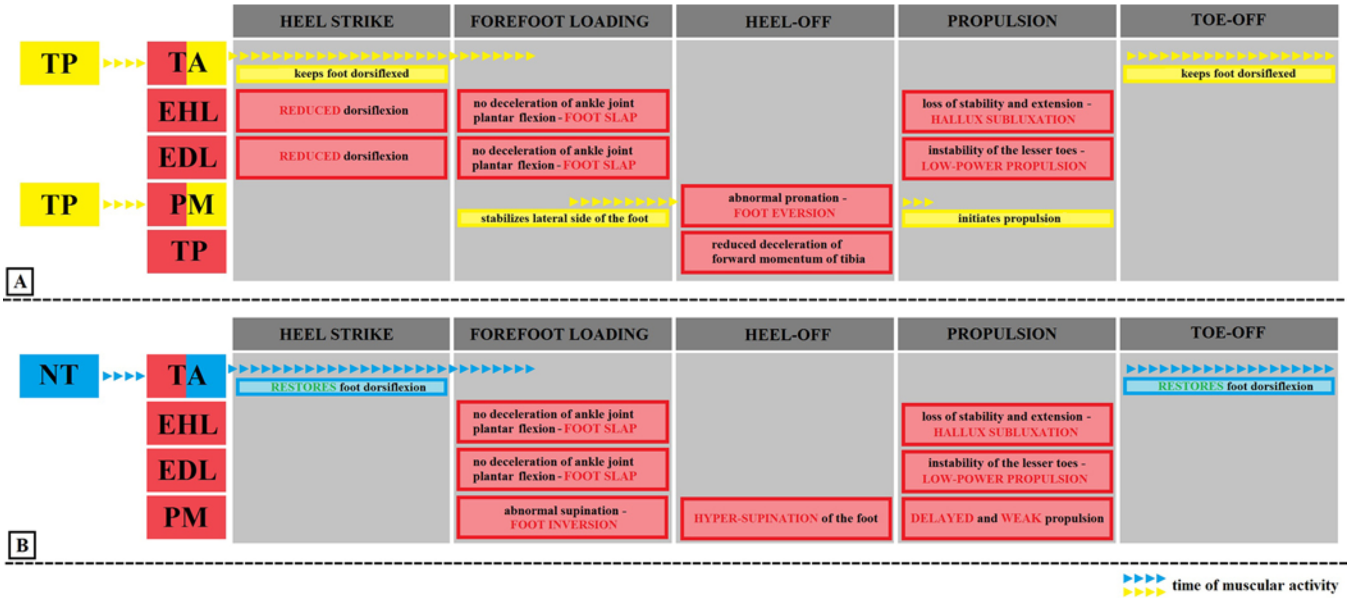

FIG. 1. Graphic representation of pathological motor phenomena during the corresponding phases of the gait cycle after MTP transfer (**A**) and partial tibial nerve transfer to the motor branch of the tibialis anterior muscle (**B**). EDL = extensor digitorum longus muscle; EHL = extensor hallucis longus muscle; NT = nerve transfer; PM = peroneus longus and brevis muscles; TA = tibialis anterior muscle; TP = tibialis posterior muscle. Figure is available in color online only.

Several surgical techniques have been proposed to improve foot drop caused by CPN injuries.[19] The strong dependence on the type of injury to the CPN noticeably narrows the pool of reconstruction strategies.[8,9,13,15]

While early direct repair of CPN lacerations brings excellent functional results, most cases of traumatic injuries to the CPN (which require grafting) were reported to be unsuccessful, especially in cases in which the grafts were longer than 6 cm.[12,24,28] Tendon transfer has been shown to improve patients' mobility and ambulation without assistive devices,[19] but provide only weak ankle dorsiflexion.[11] Successful attempts have been made to reanimate the active ankle dorsiflexion caused by CPN injuries using partial tibial nerve transfer to tibialis anterior motor branches.[5,16,19,21] These rather simplified surgical approaches appear to be successful to a greater or lesser degree, especially when the recovery of function was analyzed separately from the context of the walking process, which was a static analysis. However, only a small number of attempts have been made to analyze the compliance of de novo regained directed movements (within the complex phasic process of sequential contraction of the calf muscles) with biomechanical requirements during the gait cycle.[4,7,27]

A full gait cycle is the interval between two heel strikes (HSs) of the same foot contacting the ground.[1] The gait cycle is divided into two major parts, i.e., the stance and swing phases. During the gait cycle, muscles of the anterior, posterior, and lateral compartments of the calf tend to interact as antagonists and/or agonists, providing primarily stabilization and acceleration/deceleration to the foot. Both the interactions of calf muscles during the normal gait cycle[1] and the biomechanical alternations of gait with injury to the CPN are well studied.

All existing and, to a certain degree, proven methods for the surgical correction of muscle dysfunction caused by injuries to the CPN were aimed to restore either pronation-eversion/dorsiflexion (mimicking functions of the peroneal muscles and tibialis anterior), which is a posterior tibial tendon transfer (Fig. 1A), or dorsiflexion alone, which is a nerve transfer exclusive to the tibialis anterior motor branch (Fig. 1B). As one can derive from Fig. 1, none of the aforementioned surgical replacements of the CPN-innervated muscles fully complies with the biomechanical requirements.

Tibialis posterior tendon transfer allows one to perform active, restrained, ankle dorsiflexion (compared to the normal angle) during HS and toe off (TO)/initial swing phase by "mimicking" the lost tibialis anterior muscle function, while ensuring lateral stability of the foot and initiating propulsion during the phases of forefoot loading (FFL) and propulsion, respectively. However, a number of adverse motor phenomena remain unresolved (Fig. 1A). Pathological phenomena such as foot slap (FS), the inability to bear the entire body weight properly, and ineffective propulsion are directly linked to the malfunction of the long toe extensors during the corresponding subphases of the gait cycle (Fig. 1A). The origin of these phenomena is described elsewhere.[1] The abnormal biomechanics of the foot dramatically aggravate with partial tibial nerve transfer to the motor branches of tibialis anterior muscle. Hence, the reconstruction strategy assumes no support for the lateral aspect of the foot, because hypersupination accompanies the entire gait cycle (Fig. 1B). At the same time, the still-existing malfunction of the long toe extensors results in the above-mentioned pathological foot kinematics (Fig. 1B).

A thorough theoretical analysis of the major failures of preexisting reconstructive procedures for people with CPN injuries, viewed through the prism of physiological

TABLE 1. Demographics of patients included in the study

Case No.	Age (yrs)	Injury: Cause	Injury: Orthopedic Type	Type of Orthopedic Op	Diagnosis of CPN Injury (wks)	Duration Until Op (mos)	Intraop Findings & CPN Morphology: Anatomical Integrity	Macro View	Extent of Change (cm)
1	20	Slip	LMF	LM screw O	6	3	Preserved	No neuroma, thinned, "glassy fascicles"	Unknown
2	33	Football game	KLD	No	1	2	CPN ruptured	No neuroma, PSt thinned, "glassy fascicles"	>5
3	32	Car accident	KPD	IL EL R	9	3	Preserved	No neuroma, rigid, swollen, thickened, "glassy fascicles"	>5
4	26	Slip	LMF	LM plate O	8	2	Preserved	No neuroma, thinned, "glassy fascicles"	Unknown
5	17	Fall from a great height	KLD	LM plate O	3	4.5	CPN ruptured	No neuroma, PSt thinned, "glassy fascicles"	>8
6	23	Criminal injury	KLD	EL R	1, diagnosed at EL R	1.5	CPN ruptured	No neuroma, PSt thinned, "glassy fascicles"	>6
7	34	Car accident	KPD	IL EL R	11	3	Preserved	No neuroma, rigid, swollen, thickened, "glassy fascicles"	>5

EL = external ligaments of the knee joint; IL = internal ligaments of the knee joint; KLD = lateral knee dislocation; KPD = posterior knee dislocation; LM = lateral malleolus; LMF = lateral malleolus fracture of the fibula; Macro = macroscopic; O = osteosynthesis; PSt = proximal stump; R = reconstruction.

and pathological locomotion during the gait cycle, encouraged us to revise our surgical strategy, realizing that ankle dorsiflexion/eversion should be reconstructed on a parity basis, along with the long toe extensors, in order to satisfy the requirements of the gait biomechanics to the maximum extent feasible. The aims of the study were thus: 1) to describe the surgical technique for the partial tibial nerve transfer to the motor branches of the extensor hallucis longus muscle (MEHL) and extensor digitorum longus muscle (MEDL); 2) to clinically assess the reduction of pathological motor phenomena at the time of recovery of the long toe extensors during the gait cycle; and 3) time-dependent dynamic evaluation of the functional outcome with simultaneous nerve and tendon transfers.

Methods

Study Type

This was a retrospective single-center study of a consecutive case series from 2016 to 2018. Study inclusion criteria were: 1) complete loss of functions mediated by the CPN; 2) lack of electromyography (EMG)–based and clinical signs of CPN regeneration; 3) no severe restrictions on the passive range of motion in the ankle joint; 4) no shortening of the Achilles tendon requiring surgical lengthening; and 5) duration from initial CPN injury to reconstructive surgery did not exceed 6 months.

Patient Population

Seven male patients with traction-type injury to the CPN were included. The mean age of the included patients was 26.4 years (range 17–34 years). Five patients suffered an injury to the CPN, which was associated with high-energy trauma around the knee joint: 2 cases of posterior knee dislocation without either femoral or tibia/fibula fractures, and 3 cases of lateral knee dislocation, one of which was associated with a closed fibula fracture in its upper third. Two cases of injury to the CPN were associated with the lateral malleolus fracture of the fibula and no knee dislocation (Table 1). The average period from injury to the corresponding reconstructive surgery was 2.7 months (range 1.5–4.5 months). Two patients with posterior knee dislocation underwent surgical reconstruction of the internal and external ligaments of the knee joint prior to reconstruction of the CPN (2–4 weeks after the initial injury), and 1 patient with a lateral knee dislocation underwent osteosynthesis of the lateral malleolus of the fibula within days after the initial injury. Two patients with a lateral malleolus fracture of the fibula received osteosynthesis within the first week after the initial injury (Table 1). The injury to the CPN was diagnosed after an average of 5.5 weeks following the initial trauma, with a much earlier diagnosis in cases of lateral knee dislocation (1 week after injury), and conversely, at a later stage in cases of posterior knee dislocation (Table 1). All included patients with posterior knee dislocation stated that they experienced a weakening of the plantar flexion and foot adduction within the first weeks after the injury. At the time of inclusion, no loss of power of the tibialis posterior muscle (MTP) or triceps surae muscle was observed (Table 1).

Surgical Procedure

Nerve Transfer Technique

All patients were positioned on the operating room table on the contralateral side to the CPN injury, with additional support for the thoracolumbar spine. The intact lower extremity was flexed at the knee joint at an angle of 90°, while the injured lower extremity was extended in both the hip and knee joints. Additional support for the medial aspect of the knee joint of the injured extremity was provided with a pad. No tourniquet was applied so as to not provoke poor motor response from the tibial nerve branches.

A Z-shaped skin incision was started on the posterior

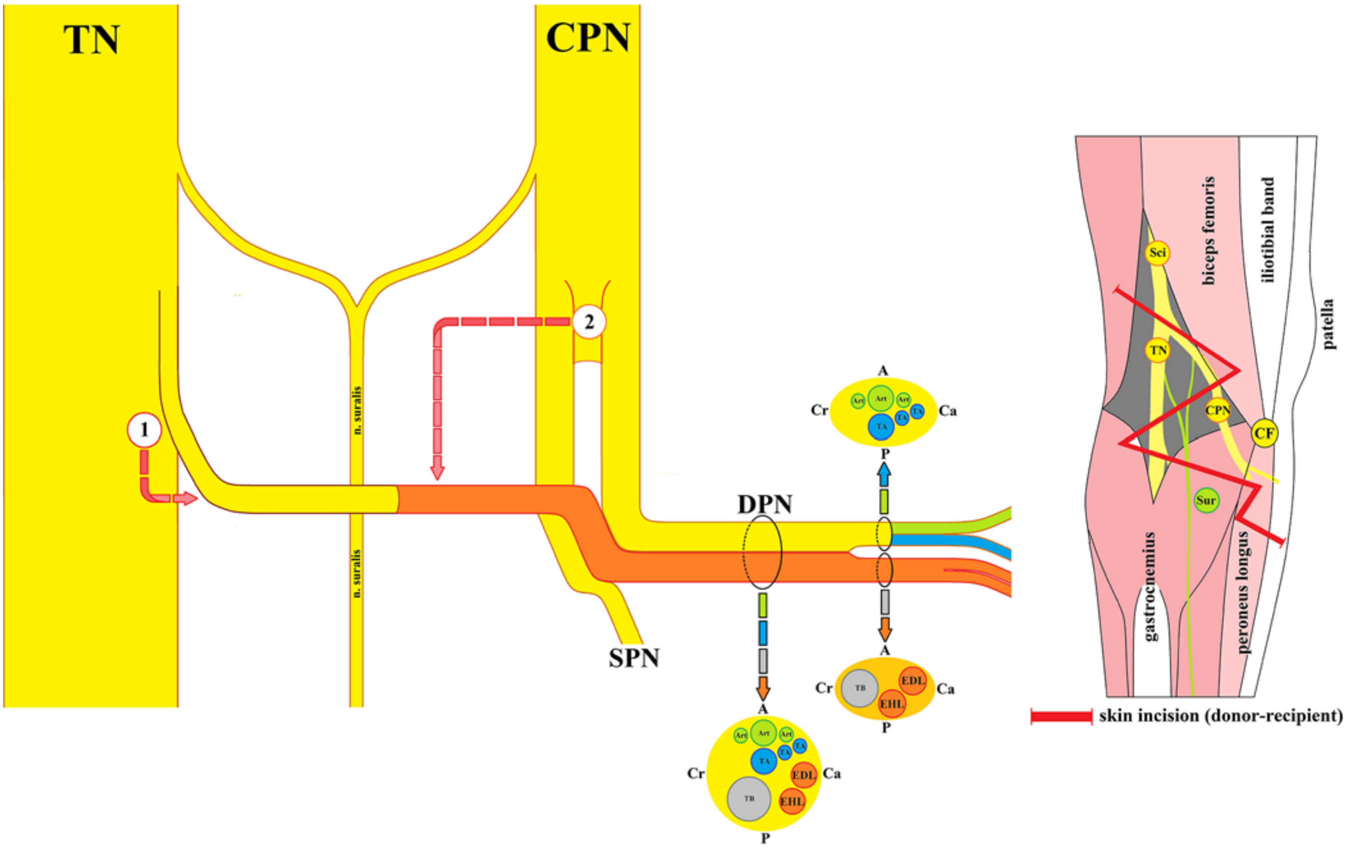

FIG. 2. Schematic representation of the partial tibial nerve transfer to the MEHL and MEDL motor branches via the direct repair technique (patients 1 and 4, see Table 1). 1 = motor branch of the tibial nerve to the lateral head of the gastrocnemius muscle; 2 = healthy-appearing fascicles to the MEHL and MEDL dissected within the CPN trunk; Art = articular branch; CF = caput fibulae; DPN = deep peroneal nerve; EDL = fascicles to MEDL; EHL = fascicles to MEHL; Sci = sciatic; SPN = superficial peroneal nerve; Sur = sural nerve; TA = fascicles to tibialis anterior muscle; TN = tibial nerve. Orientation: A = anterior; P = posterior; Ca = caudal; Cr = cranial. Figure is available in color online only.

surface of the lower third of the thigh, made a cross section of the skin fold in the popliteal region diagonally, and ended on the anterolateral surface of the ankle 2–3 cm distal to the caput fibulae. The CPN was identified at the level of the fibular neck and traced proximally toward the popliteal fossa and the lower third of the posterior surface of the thigh, under the tissue of the biceps femoris tendon and the bifurcation of the sciatic nerve, respectively. The type of CPN injury was defined in accordance with its macroscopic morphology (Table 1). As soon as the type of injury to the CPN was defined and the decision to perform nerve transfer was made, both the superficial and deep branches of the CPN were identified anatomically. The deep CPN was traced distally into the interval between the soleus and peroneus longus muscles, with partial tenotomy of the peroneal muscles, which facilitated distal dissection. Identification of the tibialis anterior muscle motor branch, the articular branch, and fascicles that contained motor branches to the MEHL, MEDL, and the terminal branch (TB) of the deep CPN was performed in accordance with the findings in the field of intraneural anatomy by Spinner et al.[26] The tibialis anterior and articular branches within the deep CPN trunk were separated from the "target" fascicles both proximally and distally. The proximal dissection of the MEHL, MEDL, and TB fascicles was performed under microscopic magnification. The dissection ended either at the level of the distal stump/level of severe thickening of the CPN main trunk (see Fig. 3), or proceeded toward the popliteal fossa to ensure the appearance of healthy fascicles (Fig. 2), which were then transected.

The tibial nerve was identified in the popliteal fossa and followed distally toward the tendinous arch of the soleus muscle. Motor branches that arise from the lateral surface of the tibial nerve were identified with the help of electrical stimuli that did not exceed 0.1 mA. As soon as the most powerful branches to the lateral head of the gastrocnemius muscle were identified, they were followed to its entry point into the muscle mass and transected. The number of branches utilized for the nerve transfer depended on the diameter of the cross section in both donor and recipient nerves to obtain perfect "size match" in the coaptation area. In 4 cases of CPN injury, nerve transfer was performed via direct repair technique (Fig. 2). Neural structures were sutured with the help of microscopic magnification (×5–8) with 9-0 to 10-0 nonabsorbable monofilament sutures in a tension-free manner, with the knee extended to 180°.

Three cases of CPN injury required graft interposition

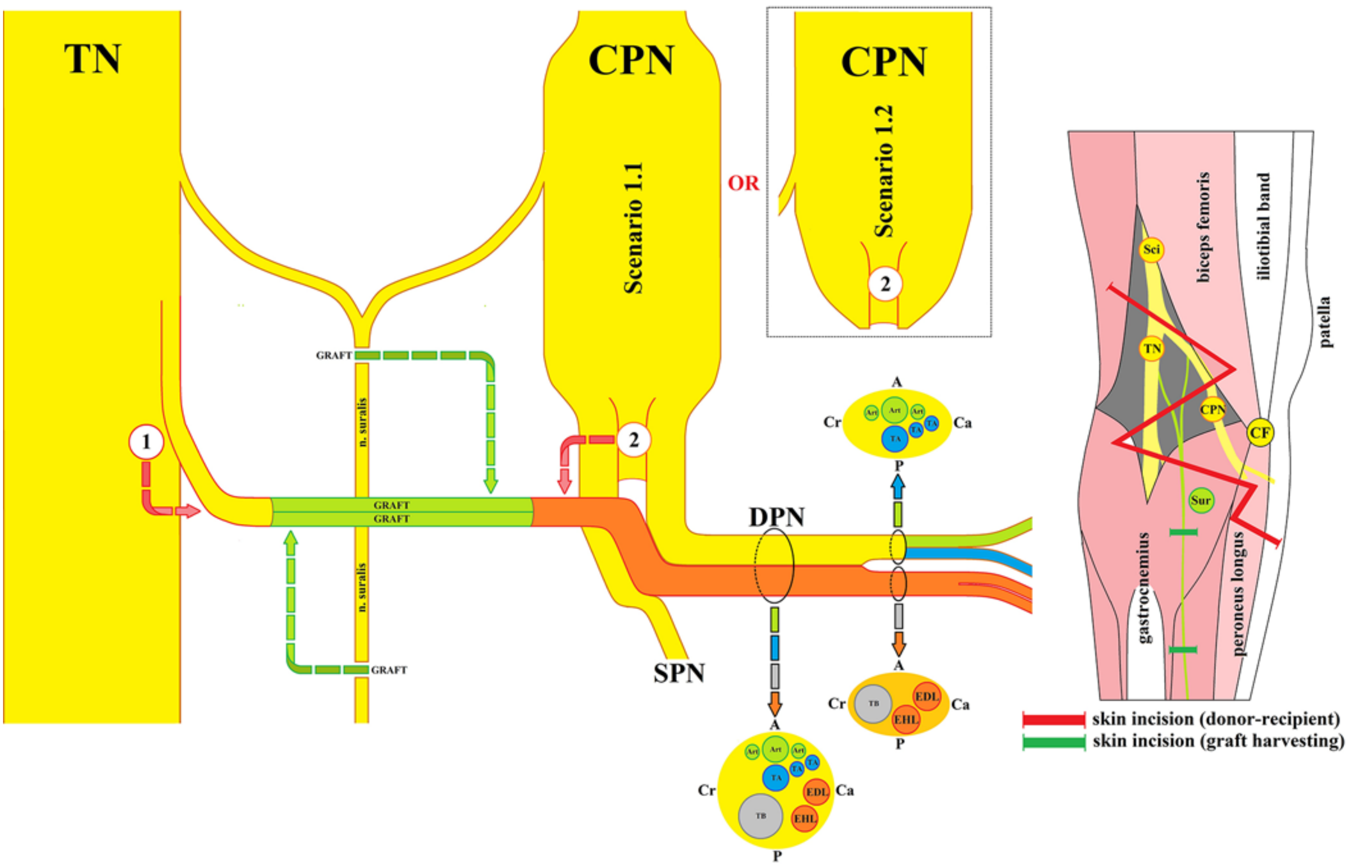

FIG. 3. Schematic representation of the partial tibial nerve transfer to the MEHL and MEDL motor branches with graft interposition: scenario 1.1, patients 3 and 7; scenario 1.2, patients 2, 5, and 6 (see Table 1). 1 = motor branch of the tibial nerve to the lateral head of the gastrocnemius muscle; 2 = healthy-appearing fascicles to the MEHL and MEDL dissected within the CPN trunk. Figure is available in color online only.

between donor and recipient nerves (Fig. 3). The main reason for graft interposition was a short recipient nerve, as proximal dissection revealed no healthy-appearing fascicles of the appropriate length. The number of grafts depended on the cross section of the donor, recipient, or both, wherein 2 grafts were required to achieve perfect "size match" in the coaptation area and to prevent the loss of valuable motor fascicles. The sural nerve was utilized as a graft and was harvested through the main exposure. Additional length of "healthier-looking" graft was harvested from small incisions on the posterior surface of the middle-third of the calf. The mean graft length was 6.5 cm. The neural structures were sutured with the help of microscopic magnification (×5–8) with 9-0 to 10-0 nonabsorbable monofilament sutures in a tension-free manner, with the knee extended to 180°.

Transfer of the MTP

The technique and outcomes of the tibialis posterior tendon transfer through the interosseous route are thoroughly described in numerous publications from around the world.[15] Early mobilization of the ankle joint was applied, which meant that active motions were allowed on the 1st, 2nd, and 3rd days after surgery, followed by 3 weeks of rigid cast immobilization of the ankle joint at 90° dorsal flexion. Both surgical procedures were performed on the same day: MTP tendon transfer followed nerve transfer surgery. All patients received standard postoperative therapy, which included antibiotics and painkillers. Neither early nor delayed complications associated with surgery were observed.

Follow-Up Period and Outcome Evaluation

All patients were examined during the follow-up period in a standardized manner. The examination included a clinical neurological examination with the evaluation of muscle strength using the Medical Research Council (MRC) grading system, modified Stanmore System questionnaire (MSSQ),[13,15] and EMG examination (both needle and surface stimulation EMG) in the 3rd, 9th, and 12th months after reconstructive surgery.

The video-based semi-subjective analysis[18] of the gait biomechanics was conducted in the 3rd and 12th months after surgery. Each patient was asked to take 25 steps with the same foot on a treadmill without additional arm support. Two video cameras captured the movements of the lower extremity in two perpendicular planes (sagittal and coronal). Video of the walking cycle of each patient was spliced into separate parts in accordance with the corre-

TABLE 2. Pathological motor phenomena in cases of injury to the CPN: movement alteration and cause

Motor Phenomena	HS		FFL		HO		TO	
	MAs	Cause	MAs	Cause	MAs	Cause	MAs	Cause
SCM	Knee hyperflexion, hip elevation	Reduced dorsiflexion, MTA					Knee hyperflexion, hip elevation	Weak propulsion, MEHL, MEDL
FS			No deceleration of PF	MEHL, MEDL				
Foot inversion			Loss of foot MLS	MEHL, MEDL, PM	Loss of foot MLS	MEHL, MEDL, PM		

MAs = movement alterations; MLS = mediolateral stability; MTA = tibialis anterior muscle; PF = plantar flexion; PM = peroneus longus and brevis muscles.

sponding subphases (HS, FFL, heel off [HO], and TO) of the gait. Twenty-five video clips of each gait subphase were combined into a single video and analyzed. The following qualitative criteria were evaluated during slow-motion video analysis: 1) in the sagittal plane, degree and timing of knee flexion/hip elevation, and fluidity of the foot/ground contact; and 2) in the coronal plane, foot positioning at the time of contact with the floor, and propulsion. To objectively evaluate biomechanical changes, all motor changes were grouped in a manner to fully comply with known pathological phenomena (Table 2).

The small number of patients did not allow for any meaningful statistical analysis. The study design did not suggest any retrospective control group. The comparison of outcomes was performed using a pre/post analysis, in which patients served as their own controls.

All procedures performed in studies involving human participants were conducted in compliance with the ethical standards of the institutional and national research committee, as well as the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Results

Overall Results

The applied MTP tendon transfer allowed us to restore the active dorsiflexion of the ankle after 3 months and enabled independent walking (without a supportive cane). Two patients still required orthoses at times (less than once a week) while taking long walks. The range of active dorsiflexion did not exceed 7° in all patients (Table 3): 3 patients (43%) showed dorsiflexion in the range of −5° to 0°, another 3 patients (43%) in the range from 0° to 5°, and only 1 (14%) showed a dorsiflexion range up to 7°. The average range of active dorsiflexion was 0.85°. No limitation in plantar flexion was observed, yet it did not exceed 25°.

All patients showed the primary sign of reinnervation of the MEHL and MEDL already at 6–7 months, which was a deep pain in the muscles of the anterior surface of the calf. Mild to moderate strength (1–3 points according to the MRC grading system) in the long toe extensor muscle was detected at 7–8 months. Stimulation of the tibial nerve in an EMG examination (the border between the lower-third of the thigh and the popliteal fossa) showed clear signs of activity within the MEHL and MEDL. The active contraction, as well as that evoked by electrical stimuli of the MEHL and MEDL, was revealed at 9 months. The average period of effective MEHL and MEDL recovery (≥ 4 points on the MRC grading system) was 11.2 months (Table 3). The range of ankle dorsiflexion increased in 4 patients due to the summation of contraction potentials of the transferred MTP and MEHL/MEDL (a more distal moment arm). Two patients were able to improve the range of dorsiflexion of the foot up to 1°–2°, and another 2 patients increased the range of dorsiflexion up to 8° (Table 3). The average range of active dorsiflexion was 4.4°.

TABLE 3. Change in the range of ankle joint dorsiflexion over time

Case No.	Range of Dorsiflexion (°)		MRC Points at 12 Mos	
	3 Mos	12 Mos	MEHL	MEDL
1	−2	+2	4	4
2	+1	+1	4	3
3	+3	+8	4	4
4	−5	+8	5	4
5	+4	+4	3	4
6	+7	+7	4	4
7	−2	+1	4	4
Average	+0.85	+4.4		

Results of the Semi-Subjective Video-Based Gait Analysis: Changes in Foot Biomechanics

Three months after the MTP tendon transfer and the continuing regeneration of the long toe extensors, a video-based analysis of the foot biomechanics revealed the presence of three main pathological motor phenomena during the corresponding gait phases (Fig. 4). Limited foot dorsiflexion in 6 (86%) of 7 patients resulted in knee hyperflexion and hip elevation (stair-climbing maneuver [SCM]) during the terminal swing and HS phases. The FS against the ground during the FFL subphase was primarily associated with the absence of deceleration forces produced by the MEHL and MEDL in 3 patients (43%). Another 3 patients (43%) avoided the FS by planting the entire foot on the ground, which was accompanied by an increase and prolongation of knee flexion/hip elevation. Only 1 pa-

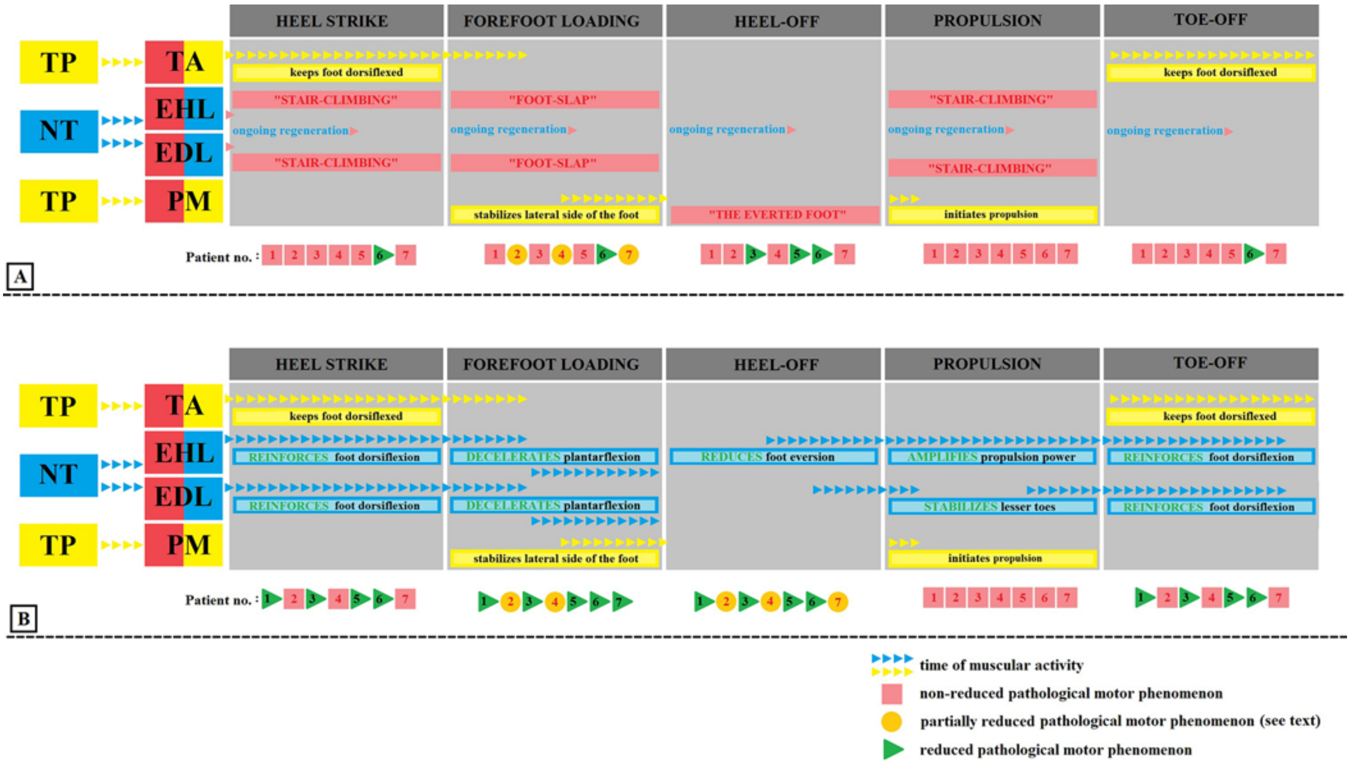

FIG. 4. Graphic representation of pathological motor phenomena during the corresponding phases of the gait cycle: 3 months (**A**) and 12 months (**B**) after surgery (at the time of MEHL and MEDL recovery). Figure is available in color online only.

tient experienced no problems with foot deceleration, most probably due to the significant independence of the transferred MTP. The foot eversion was clearly visible during the terminal FFL and initial HO in 4 of 7 patients (57%). All patients required additional orthopedic support (shoe inserts) to compensate for mediolateral foot stability during weight bearing of the body. The weakened propulsion in all 7 patients during the subphases of propulsion and TO resulted in an SCM similar to that seen at high-steppage gait.

Twelve months after MTP tendon and partial tibial to MEHL/MEDL motor branch transfers, the video-based slow-motion analysis of foot biomechanics revealed a partial reduction of pathological motor phenomena during the corresponding gait subphases (Fig. 4). Increased range of ankle joint dorsiflexion (mediated by recovered MEHL/MEDL with their more distal moment arm) resulted in the reduction of SCM in 4 of 7 patients (57%, 3 more patients compared to MTP function only) during HS and TO subphases, respectively. The deceleration forces of the recovered MEHL/MEDL produced the reduction of the FS in 5 of 7 patients (71%, 4 more patients compared to MTP function only). Two patients (29%), 1 occasionally and 1 rarely (9 and 4 times out of 25, when the affected foot took part in the whole gait cycle), planted the entire foot on the ground. During the HO subphase the recovered function of the MEHL led to a reduction of excessive foot eversion in 4 patients (57%). Another 3 patients (43%) required no specific orthopedic inserts to compensate for the weak mediolateral stability of the foot. The amplified propulsion force mediated by the recovered MEHL resulted in a reduction of SCM in 4 of 7 patients (3 more patients compared to MTP function only) during the TO subphase.

Results of the Functional Assessment of Walking (MSSQ Scores)

Three months after surgery, the mean MSSQ score was 80.4 points, which was between a "good" and "fair" outcome (Fig. 5). Twelve months after surgery, the mean MSSQ score was 92.4 points, between a "good" and "very good" outcome (Fig. 5). The average increase in MSSQ score was 12 points. The sections within the MSSQ that provided an increase in the total score were as follows: range of foot dorsiflexion, 4 patients; shoe wear, 4 patients; pain reduction, 3 patients; need for orthoses, 2 patients; etc.

Discussion

Injury to the CPN is the most common mononeuropathy of the lower extremity.[14] Several authors have reported a series of cases of CPN injury associated with knee dislocation.[6] Traction-type injury to the CPN occurs in 25%–30% of all cases of knee dislocation,[25] and up to 40% of knee dislocations lead to rupture of the neurovascular bundle within the popliteal region.[3] Injury to the CPN results in dramatic changes in gait biomechanics: steppage gait or SCM (due to loss of ankle dorsiflexion), FS (due to loss of foot deceleration, provided by the long toe extensors), hyperinversion (due to loss of foot abduction, provided by the peroneal muscles), and up to 35% of limb disability.[2]

It has been reported that different surgical strategies for repairing complete injury to the CPN lead to differ-

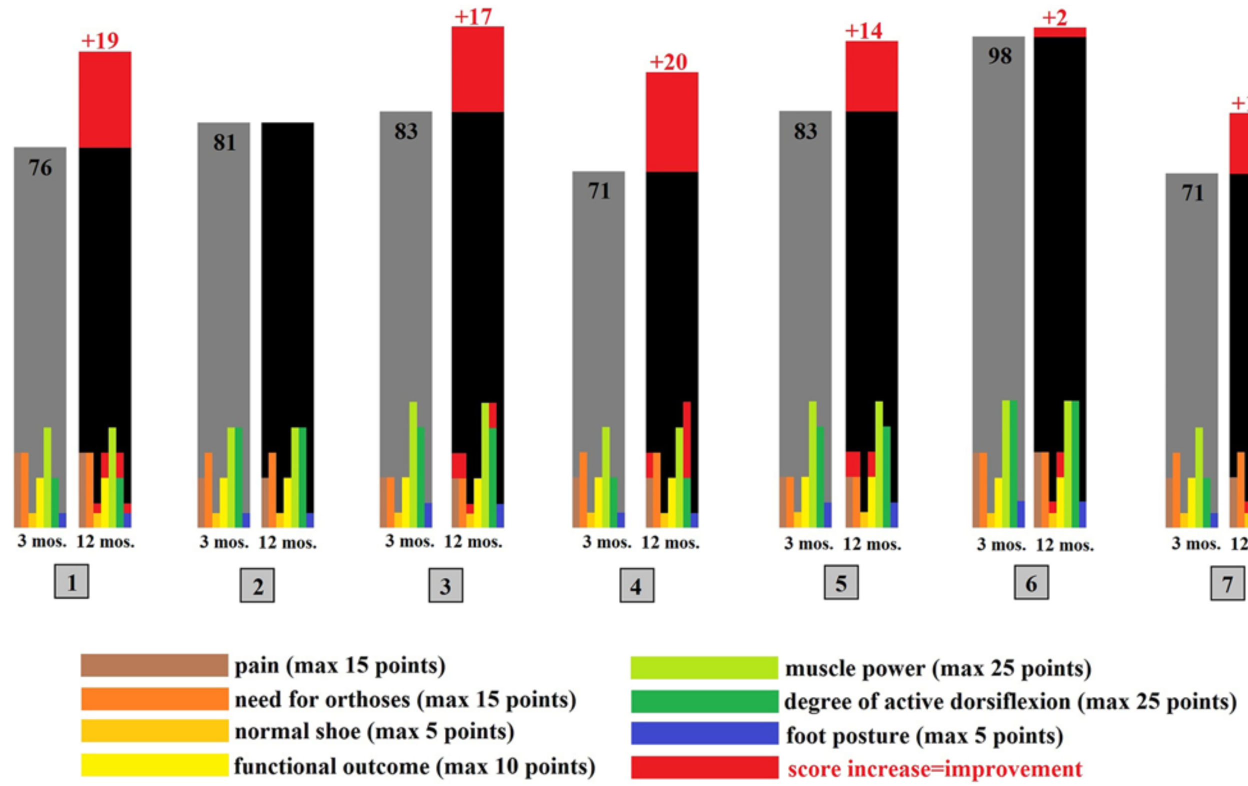

FIG. 5. Dynamics of change in the MSSQ score in all 7 patients at 3 and 12 months after surgery. Figure is available in color online only.

ent rates of positive outcomes: direct repair results in successful recovery of function in roughly 84% of cases, and grafting results in a 75% success rate of restoration of function with a graft length less than 6 cm, with a significantly decreased rate of recovery of function of up to 16% with an increase in graft length.[13] The cases of irreparable injuries to the CPN are very treatable by various techniques using single- or double-tendon transfer procedures, and they have proven to be effective for decades.[8,15] Their limitations and disadvantages have also been described.[8,15]

A thorough study of intraneural anatomy led to the emergence of an alternative nerve repair technique, namely distal nerve transfer.[17,22,23] This technique also did not spare CPN injuries. The precise methodology of reinnervation of the tibialis anterior muscle was shown and the results appeared to be promising.[9,20] The idea of combined nerve and tendon transfers was suggested by Giuffre et al.[5] Yet, the target for reinnervation remained the same (which was the tibialis anterior), and the objective was to increase the range of dorsiflexion.

We consider that significant differences in upper- and lower-extremity biomechanics do not allow a surgeon to transfer the reconstructive approaches in a simplified manner. The role of the lower-extremity muscles in human walking is much more complicated. Hence, the reconstruction strategy should consider biomechanical requirements as a prerogative. Wise selection of the reinnervation target becomes a major goal. The proposed technique of simultaneous tibialis posterior tendon transfer and reinnervation of the long toe extensors was aimed to primarily influence gait biomechanics by providing stabilization, acceleration/deceleration to the foot, along with the return of principal CPN-mediated functions.

The study findings revealed a partial reduction of SCM and hyperinversion of the foot with MTP tendon transfer 3 months after surgery. Slapping and hypereversion of the foot still accompanied the walking process. Regeneration of long toe extensors was still ongoing.

Complete independence of the long toe extensors (recipient) from the muscles of the posterior compartment of the calf at the time of recovery (12 months after surgery) was revealed during EMG examination. Fluent consequent contraction of the regenerated long toe extensors found its clinically visible reflection in reduction of the FS. Hypereversion was reduced in the majority of patients. The SCM was still present at the later stages of recovery, regardless of the fact that the foot dorsiflexion range increased.

Reduction of pathological motor phenomena with the recovery of the long toe extensors led to an increase in patients' functional perception of the injured lower extremity during daily walking.

In this report, we offer our experience with the simultaneous nerve and tendon transfers described. This technique may be useful for the management of some patients with this devastating injury. The encouraging, although preliminary, results allowed us to adopt this technique in our department. Considering the limitations of this study, further investigation is needed. The accumulation of results could possible widen the indication spectrum for this particular procedure.

Limitations of the study include: 1) a small number of patients; 2) variability of injury to the CPN (complete/incomplete lesion, etc.); 3) variability of the nerve transfer technique, i.e., direct versus graft repair that may confound the results; 4) semi-subjective video-based assessment of the ankle and foot biomechanics; and 5) a relatively short follow-up period, which did not exceed 12 months.

Conclusions

In our series, we found that the partial tibial nerve transfer to the motor branches of the extensor hallucis longus and the long toe extensors, along with the simultaneous tibialis posterior tendon transfer, improves patients' gait biomechanics. The recovery of long toe extensors produces a reduction of FS and brings mediolateral stability to the foot. The reduction of pathological motor phenomena at the time of recovery of the long toe extensors is reflected in the increased individual functional perception of the injured lower extremity during daily walking.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Gatskiy. Acquisition of data: Gatskiy, Tretyak, Tretiakova. Analysis and interpretation of data: Gatskiy, Tretyak, Tretiakova. Drafting the article: Gatskiy, Tretyak. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Gatskiy. Administrative/technical/material support: Tsymbaliuk. Study supervision: Tretyak.

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