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Results of Neurogenic Foot Deformities Treatment in Children by the Method of Tendon-Muscle Transposition

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Abstract

Neurogenic foot deformities caused by the damage to peripheral nerves always represent one of the most difficult and urgent tasks in traumatology and orthopedics in children. Main manifestations of this disease are difficulties in walking. An objective evaluation of these difficulties and functional outcome represents some problems because of the subjective perception of motor abnormalities during clinical examination of patients. The aim of this study was to assess the results of treatment of neurogenic foot deformity in children after tendon-muscle transposition by clinical gait analysis (CGA). One hundred twenty-nine patients aged from 3 to 18 years with neurogenic deformities of the lower extremities were examined and treated with tendon-muscle transposition. CGA was used combined with a dynamometric platform for an objective assessment of restoration of the affected limb function, as well as its support ability in the long-term period. It revealed different graphical pictures in terms of support reactions and pressure under the foot. This was entirely dependent on the type of tendon-muscle transposition. The conducted analysis showed an improvement of kinematic parameters of the knee and ankle joints. This was the asymmetry parameter (claudication) to be the main post-operative modified indicator. CGA with the formation of the standard CGA protocol has a great potential in the objective assessment of long-term treatment results. The conducted comprehensive CGA in neurogenic foot deformities revealed positive outcomes that exhibit improved quality of walk parameters.

Keywords

Neurogenic foot deformities in children; Tendon-muscle transposition; Asymmetry parameter; Clinical gait analysis

Introduction

Neurogenic foot deformities caused by the damage to peripheral nerves always represent one of the most difficult and urgent tasks in traumatology and orthopedics in children. The rate of nerve injuries varies from 1 to 10% of the total musculoskeletal injuries [1,2], while the rate of peripheral nerve injuries of the lower extremities remains to be high among all nerve trunk injuries ranging from 9 to 20% [3-6]. These deformations are the result of damage to the sciatic nerve and its branches, as well as its inadequate treatment. Its frequency varies from 9 to 75% and depends on the nature and the level of the damage and on its remoteness [1,7,8].

The leading mechanism in the development of neurogenic deformation is the violation of nerve impulses conduction leading to denervation of the vascular wall, and its tone. Consequently, blood flow also deteriorates. An absence of contractility of the lower extremities muscles (that have the function of “muscle pump”) plays a prominent role by violating lymphatic and venous outflow. Extensive heterogeneous regions of muscle tissue with intracellular changes and mitochondrial swelling due to loss of cristae and matrix were revealed by light microscopy in the experiment in denervated muscle of rats performed in 2 weeks after sciatic nerve injury. All this led to the apoptosis of myocytes, and 1 month later transverse muscle striation almost completely disappeared [9].

The clinical picture of damages to the sciatic nerve covers the area that is predominantly affected: tibial or fibular. An appearance of deformation corresponds to the typical pattern of damage to these nerves. In most cases, neurogenic foot deformities are based on the absence of active dorsiflexion at the ankle joint being the end result of various processes caused by different neurological disorders, systemic and infectious diseases, as well as traumatic injuries [10-13]. The main manifestations of this disease are difficulties in walking. An objective assessment of these difficulties and functional outcomes represents some problems because of the subjective perception of motor abnormalities during clinical examination of patients. Tendon-muscle transposition (TMT) is a “gold standard” in the treatment of neurogenic foot deformities. An operation includes the replacement of paralyzed muscles by non-paralyzed ones with subsequent retraining. The aim of TMT is to restore active movements in the paralyzed joints in order to improve their support ability. It allows restoring the foot function in a maximum physiological way through achievement of muscular balance [14].

High interest in obtaining objective data about the walk parameters initiated lab development of the technologies on movement registration. These measures led to the development of software and hardware systems that help you to analyze the movement in the clinical setting. These systems work on the basis of different physical phenomena. Standardized international protocol named “clinical gait analysis (CGA)” was developed for the unification of the results.

Thus, foot deformities caused by the damage to peripheral nerves, in children, impose a significant imprint on social adaptation and as a consequence lead to reduced quality of life.

The aim of the study was to assess the results of treatment of neurogenic foot deformity in children after TMT by CGA.

Materials and Methods

We observed 129 patients with neurogenic deformities of the lower extremities characterized by the lack of dorsiflexion, treated...
by TMT in the Pediatric Trauma Department of the Central Institute of Traumatology and Orthopedics named after N.N. Priorov (1993–2013). There were 72 (55.8%) boys and 57 (44.2%) girls aged from 3 to 18 years.

Indications for surgical treatment were determined individually and depended on the duration of muscles denervation and the severity of irreversible changes.

In most cases, all violations were manifested by motor and sensory disorders with partial or complete loss of muscle function. Fifty-two (40.3%) patients with neurogenic foot deformities were operated in the period from 1 to 3 years. Most of the patients (75 subjects, 58.1%) were hospitalized after 3 years from the time of the injury and had heavy rigid deformations. This is caused by irreversible degenerative changes in denervated muscles which occur within 12 months after the injury and secondary changes in capsule-tendon apparatus and osteochondral elements of the limb. This particularly explains the severity of the advanced deformation. Severe changes in the damaged nerve over a large area were revealed only in 2 patients (1.6%) in the period up to 1 year from the injury, during the surgical operation. These changes made it impossible to restore the nerve function and served as an indication for one-stage TMT.

In our study we used ELITE BTS apparatus (Italy) based on the motion-capture technique in order to obtain objective results. The video recording system was combined with a dynamometric platform allowing registering the motion trajectory of the resultant foot reaction. The results of the studies were in accordance with international CGA protocol. The protocol includes temporal, spatial, kinematic, and kinetic parameters. It also provides normalized data calculated with the use of the individual age, anthropometric indicators, and sex of the tested subject.

In order to determine the degree of claudication (asymmetric type of walking), we used a specific index, the asymmetry parameter (PA), which was calculated as the ratio of the support periods (SPs) of the injured limb to the healthy one [15]:

$$PA = \left(1 - \frac{\text{smaller SP}}{\text{bigger SP}}\right) \times 100\%$$

In assessing the PA, we consider the rate of up to 5% as normal, while larger values are considered as pathological asymmetry. Hidden claudication is diagnosed from 5 to 10% using biomechanical equipment, and more than 10% is treated as an obvious claudication [16].

Surgical treatment of neurogenic foot deformities after injury of the fibular portion of the sciatic nerve or common peroneal nerve performed in 83 patients was aimed at restoring the active dorsiflexion of foot and extension of toes by transplanting the tendon of musculus tibialis posterior through the gap to the tibiofibular metatarsal bone of the foot. This procedure was combined with the transposition of the flexor digitorum longus on the extensor digitorum.

Surgical Technique

From the cut on the inner surface of the foot, we isolated the tendon of m. tibialis posterior and the tendon of musculus flexor digitorum longus (Figure 1a). Through the additional incision in the middle and lower third of the crus, we took these tendons out (Figure 1b). In order to compensate for the lack of the tendon’s length, we collected the tendon from the paralyzed muscle, musculus peroneus longus, as it had lost its function irreversibly and was not involved in the muscle balance of the foot. Collection of the graft was performed from two incisions: distal part in the base of metatarsal bone V and proximal part of the tendon at the place of its transition into the muscle. In this case, the proximal part (muscular one) was sutured to the tendon of musculus peroneus brevis (Figure 1c). Then a channel was formed using forces through the tibiofibular space followed by performing an additional incision in the frontal leg surface. Both tendons were taken into the wound through this additional incision (Figure 1d). Extensor tendons of toes I and II–V were isolated on the dorsal surface of the foot through a wave-like incision followed by an access to the metatarsal bone. Then the tendons were taken to the dorsal surface of the foot by forces through the incision in the frontal surface of the crus. These tendons were fixed in a new place under physiological tension at a slightly hypercorrected position of the foot. A free autograft was placed around the metatarsal bone in the form of a loop (Figure 1e). The tendon of m. tibialis posterior was fixed to the autograft (Figure 1f) and the tendon of m. flexor digitorum longus— to the tendons of paralyzed extenders of I and II–V toes (Figures 1g and 1h). The wounds were sutured in layers. In case of tension of the Achilles tendon and the impossibility of foot movement in the proper physiological position, we performed the Achilles tendon lengthening.

Neurogenic deformation caused by the loss of deep peroneal nerve branches function or partial damage to the sciatic nerve branches is defined as lesion of anterior leg muscles. In most cases, this type of damage affects musculus tibialis anterior with or without involvement of the toes extensors.

Forty-six patients with injuries of the deep branch of the peroneal nerve of traumatic nature, as well as neuromuscular disorders, underwent course of the treatment. The main type of TMT in these patients was transplantation of m. peroneus longus on the dorsal surface of foot.

Surgical Technique

The tendon of m. peroneus longus is mobilized and cut off at the base of the metatarsal bone V (Figure 2a). Through the additional incision in the middle and lower third of the crus, tendons were placed outside (Figure 2b). Through the wave-shaped incision on the dorsal surface of the foot, we separated the selected metatarsal bone in layers for the site of attachment. Using forces in the subcutaneous fat and under retinaculum musculorum, we formed a tunnel through which the transplanted tendon was placed on the dorsal foot surface. The tendon of m. peroneus longus in the form of loop was placed under metatarsal bone and sutured (Figure 2c). In five patients this method was combined with transplantation of m. flexor digitorum longus onto toes extensors.

In 49 (30.43%) patients of the older age group, TMT was combined with three-articulation subtalar arthrodesis. Such approach was used in severe, rigid neurogenic deformations with considerable changes in the bones and articulation elements of the foot. In 18 (36.73%) cases arthrodesis and TMT were carried out in one stage, while in 31 (63.27%) cases arthrodesis was carried out in the long-term period after TMT. This was carried out in subjects with secondary deformity of the foot caused by muscle imbalances due to the child's physical growth, incorrectly selected fixation point, and weakness of the transplanted muscle. Such patients represented 19.25% of the total...
Figure 1: Stages of tendon-muscle transposition performed for common peroneal nerve injury. Explanation is in the text.

Figure 2: Stages of tendon-muscle transposition for the damaged deep branch of peroneal nerve. Explanation is in the text.
Results and Discussion

According to the CGA conducted in 19 patients before the surgery, we revealed that the effect of changes in the kinetic parameters of the damaged foot is a significant increase in pathological load on knee and hip joints. This load subsequently led to changes in time parameters of walking and overload of the healthy limb (Figure 3), which were manifested in the decrease in support time for the injured limb and increase in this parameter on a healthy side ($p = 0.0002$). Asymmetry parameter on the average was equal to 13.4% (obvious claudication).

In the group of 42 patients who had undergone TMT aimed at the restoration of active foot dorsiflexion in the post-operative period from 1 to 20 years, this study was aimed to assess the recovery of affected limb function, as well as its support ability.

The analysis of support reactions and pressure under the foot gave us different graphical pictures, which were entirely dependent on the type of TMT. So, in 18 (43%) patients after m. tibialis posterior tendon transposition on the metatarsal bones and m. flexor digitorum longus transposition on the extensor digitorum, graphics parameters (Figure 4a) of the pressure under the foot showed a slight overload of the medial part of the foot. This fact was caused by collection of m. tibias posterior involved in the formation of the foot arch. However, this muscular imbalance was compensated by wearing of orthopedic insoles and arch supports, and did not deliver any inconvenience to patients.

In 14 patients who underwent m. peroneus longus tendon transposition, we revealed dual graphic picture of the reaction and pressure under the foot. Thus, in six patients after TMT procedure without the use of three-articulation subtalar arthrodesis, we noticed an overload of the lateral part of the foot (Figure 4b) caused by muscle imbalance due to powerful elastic recoil of m. tibialis posterior and weakness of m. peroneus brevis.

Figure 3: Goniograms of ankle (a) and knee (b) joints during walking before the surgery. Red line—the injured limb, green line—healthy one, and gray line—normal range

Figure 4: Chart demonstrating an overload of the medial part of the foot (a) after transplantation of the posterior tibial muscle, and (b) after transplantation of m. peroneus longus without the use of three-articulation subtalar arthrodesis. Green Line—damaged foot, red line—healthy one, and gray line—normal range

Figure 5: Goniograms of knee (a) and ankle (b) joints. The lack of high amplitude of excessive knee flexion and beginning of foot dorsiflexion. Red line—the injured limb, green line—healthy one, and gray line—normal range

Figure 6: Vertical component of post-operative support reaction. Red line—the injured limb, green line—healthy one, and gray line—normal range

Table 1: Temporal step characteristics

<table>
<thead>
<tr>
<th>Time characteristics of the step</th>
<th>Healthy limb</th>
<th>Injured limb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support period before the operation, n = 19</td>
<td>0.72; 0.77; 0.79</td>
<td>0.64; 0.68; 0.72*</td>
</tr>
<tr>
<td>Support period after the operation, n = 42</td>
<td>0.62; 0.65; 0.71</td>
<td>0.60; 0.64; 0.69*</td>
</tr>
</tbody>
</table>

*p = 0.26 (U-test)
The analysis of kinematic parameters indicates improved goniographic parameters in the knee joint. In 30 (71.4%) subjects, the pathological symptom of excessive flexion of the knee joint, which occurs in patients with damage to the peroneal nerve and has a curve with high amplitude on the graph, almost was eliminated. This fact indicates the proper work of the transplanted muscles, aimed at foot dorsiflexion, and the absence of steppe gait (Figure 5).

Improvement of the vertical component of dynamic parameters of the injured limb was an irrefutable fact. This was manifested in the appearance of the posterior front of support reactions due to foot dorsiflexion on walking. Similar picture was observed in 30 (71.4%) patients in the long-term period after the conducted surgical treatment (Figure 6).

In the analysis of gait violations, we took into account the degree of asymmetry of the injured limb as compared with the healthy one, and character of the motility disorders of the joints, which revealed a positive change of walking.

The PA was the main modified post-operative indicator. On the average it decreased down to 5.8%. Using the available data of functional asymmetry of single SP in the step cycle, the results after the surgical treatment were classified as follows: good result was observed in 22 (53.7%) patients, satisfactory result (hidden claudication)—in 12 (26.8%) patients, and unsatisfactory result (obvious claudication)—in 8 (19.5%) patients.

The analysis of the statistical data revealed considerable changes in the parameters of SP before (0.72; 0.77; 0.79) and after (0.62; 0.65; 0.71) surgical treatment of healthy limbs (p = 0.0001, U-test). However, there were no considerable differences in the parameters of the injured limb before and after surgical treatment (p = 0.07, U-test).

Conclusion

The conducted comprehensive CGA in cases of neurogenic foot deformities revealed positive results of treatment in 80.5% of cases in the form of improved quality of gait parameters. The findings suggest an improvement in the post-operative support ability of the injured limb and reducing a compensatory overload on healthy contralateral limb.

CGA with the formation of the standard CGA protocol has a great potential in the objective assessment of the long-term treatment results. The revealed locomotor gait disorders seem to be a pathological strain on knee and hip joints of the damaged limbs, causing considerable violations of the support reactions and overloading of the healthy limb. This confirms the necessity for timely implementation of reconstructive and plastic surgery.

The TMT is an effective way of correcting neurogenic foot deformities in children. This operation makes it possible to eliminate muscle imbalances and provides a basis for the normal functioning of the denervated limb.

The emergence of muscle deficiency as the child grows following TMT serves as a cause of secondary deformation and requires interventions on osteo-articular elements.

Three-articulation subtalar arthrodesis as a way to correct residual foot deformations in the long-term period following TMT creates favorable conditions for the functioning of the transplanted muscle.

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References