Long term course of the H reflex after selective tibial neurotomy

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Objectives: This study was conducted to evaluate the long term clinical and electrophysiological outcome by recording the H reflex in a consecutive series of six patients treated by selective tibial neurotomy for spastic equinus foot.

Method: The amplitudes of Hmax reflexes, Mmax responses, and Hmax:Mmax ratio were recorded in six patients with chronic lower limb spasticity, before and after surgery, at day 1 and 8 months and 24 months after selective tibial neurotomy. The passive range of movement, the stretch reflex score according to the Tardieu scale, the osteoarticular and tendon repercussions, and the quality of motor control of dorsiflexion were evaluated preoperatively and postoperatively.

Results: At the end of the study, all patients presented a reduction of equines. Gait and Tardieu's score of spasticity had improved in all patients. Active dorsiflexion of the ankle was unchanged in four patients, but two improved by 5° to 12°. In five cases, fascicular resection of the superior nerve to soleus was, alone, sufficient to reduce spastic equinus foot, without recurrence, for a mean follow up of 28 months. Two patients were reoperated on, one for remaining spasticity related to an underestimated spasticity of the gastrocnemius muscles, and the other for painful claw toes. Hmax, Mmax, and Hmax:Mmax ratios were significantly lower the day after surgery. The reduction of Hmax and Hmax/Mmax ratio remained stable over time and was still statistically significant two years after the operation. However, the value of Mmax eight months postoperatively was no longer significantly different from the preoperative value.

Conclusion: This study shows the long term efficacy of the selective tibial neurotomy as treatment of spastic equinus foot. Neurotomy confined to fibres supplying the soleus muscle is sufficient in most cases and acts by decreasing sensory afferents without significant long term motor denervation.

Spasticity is defined as hyperexcitability of the myotatic reflex causing velocity dependent exaggeration of the stretch reflex and deep tendon reflex.¹ Electrophysiological recording of the H reflex² and determination of the ratio of the maximum amplitude of this reflex response (Hmax) over the maximum amplitude of the direct motor response (Mmax) measures the excitable fraction of the spinal cord motoneuron pool participating in the myotatic reflex.^{3–7} An increase in the Hmax/Mmax ratio greater than 0.5 indicates that more than one half of the motoneuron pool is excited by stimulation of afferents derived from this muscle. It is considered to accurately reflect excitability of the motoneuron pool of the muscle recorded. This quantitative approach is one of the methods used to assess spasticity, which is a complex syndrome involving spinal reflex and peripheral changes within the muscles themselves.^{8–10}

Spastic equinus foot is very frequent in hemiplegic patients. In the absence of effective medical treatment (including botulinum toxin or alcohol injection), this deformity can be treated by selective tibial neurotomy.¹¹ This operation consists of partial resection of the motor branches of the triceps surae muscle heads. A study of the course of the H reflex after neurotomy showed that this partial resection concerned Ia afferents more than motoneuron axons, as the Hmax/Mmax ratio measured two months postoperatively was significantly decreased.³ Tibial neurotomy can therefore be used to considerably decrease spasticity without inducing excessive muscle paralysis. Axonal regeneration phenomena and distal collateral sprouting observed in the long term follow up of peripheral nerve lesions,^{12–16} together with the lack of clinical studies on the long term outcome of operated patients, raised doubts about the long term efficacy of tibial neurotomy in the treatment of spastic equinus foot.

The objective of this study was to evaluate the long term clinical and electrophysiological efficacy by recording the H reflex in a consecutive series of six patients treated by tibial neurotomy for spastic equinus foot.

METHODS

Clinical material

Study population

Six patients (three men, three women) with spastic equinus foot were operated by fascicular tibial neurotomy. The mean age of the patients at the time of the operation was 28 years (SD 13 years). The aetiology of equinus foot was diplegia because of prematurity in one case, paraparesis because of Strumpell Lorrain syndrome in one case, tetraparesis because of Arnold-Chiari malformation in one case, hemiplegia in three cases (ischaemic stroke in one case and head injury in two cases). The interval between the neurological accident and treatment ranged from eight months to 12 years (mean (SD) 67 (61.4) months), with a stabilised neurological state.

Clinical characteristics

The passive range of movement, the stretch reflex score according to the Held-Tardieu scale,^{7 17–19} the osteoarticular and tendon repercussions, and the quality of motor control of dorsiflexion were evaluated preoperatively and postoperatively.

All patients complained of gait disorders, attributable to spastic equinus foot. All patients presented severe equinus foot with a score of 2 on a 3 point scale (0=absent; 1=moderate, absence of second rocker at the stance phase; 2=severe, absence of heel strike).

Exaggeration of the stretch reflex (Held-Tardieu score =1) was demonstrated in every case, with the knee flexed or extended, indicating soleus spasticity.²⁰

All patients presented clonus with the knee flexed, which was inexhaustible in six cases (score 4) and exhaustible in one case (score 3).

With the knee in extension, inexhaustible clonus was detected in five cases (score 4), exhaustible clonus (score 3) was observed in one case and jerking (score 2) was observed in one case.

Spastic equinus foot was not accompanied by excessive tendon retraction. The passive range of movement of the ankle in dorsiflexion, with the knee extended, was equal to 5° in five of six patients; one patient showed early signs of retraction with an angle of 0°.

In three patients, equinus foot had caused repercussions on the knee, in the form of genu recurvatum.

Motor control of dorsiflexion (tibialis anterior, extensor digitorum) was only observed in two of six patients and was only expressed synkinetically.

Study design

Clinical evaluation by motor block

Preoperative clinical evaluation comprised a selective motor block in three of six patients, consisting of injection of ethidocaine (Duranest, AstraZeneca, Wilmington) in contact with a motor nerve to confirm participation of the various branches of the tibial nerve in the foot deformities (equinus, varus, claw toe). For the three remaining patients, test by motor block was not needed because they presented with an equinus foot only. The injection site was determined by anatomical landmarks and the nerve was located by means of a stimulation technique. Proximity of the nerve was confirmed when stimulation triggered contraction at an intensity less than 0.30 mA.²¹ This test, by eliminating any nervous control, was used to evaluate the role of the spasticity induced by the infiltrated nerve in the impaired mobility of the joint concerned; it also provides the patient with a useful idea of the expected result of surgery.⁵

Surgical technique

Patients were operated under general anaesthesia. Drugs were used at a dose known not to interfere with motor neurons excitability.²²

Surgical procedure consisted of selective neurotomy—that is, partial fascicular section—of the motor branches of the nerves to the triceps surae.¹¹ Two patients were operated on the left side, three on the right side and a bilateral procedure was performed in one patient.

Nerve branches supplying the soleus, gastrocnemius, flexor digitorum, and tibialis posterior muscles were exposed and dissected, case by case, according to their participation in the spasticity, as determined on preoperative evaluation.

Selective tripolar stimulation (impulse time: less than 0.1 ms; intensity of stimulation: 0.5 to 2 mA) was performed to identify each motor nerve structure, by demonstrating the nature of the muscle controlled by visual analysis of the type of movement induced.

The efficacy of the procedure was correlated with intraoperative resolution of clonus.²³

A neurotomy of the superior nerve to soleus was performed in every case—that is, seven times in six patients (bilateral neurotomy was performed in one patient). The extent of the neurotomy was estimated to be 80% in five cases, 75% in one case, and 60% in one case.

The presence of clonus was tested during the operation. Immediate resolution of clonus was observed in every case, eliminating the need to extend the neurotomy to the motor branches of other muscle heads of triceps surae.

The anti-equinus neurotomy was isolated in five cases and associated with another neurotomy in two cases (80% neurotomy of flexor hallucis longus and 80% neurotomy of flexor digitorum longus in one case to treat associated claw

toes; 66% neurotomy of tibialis posterior, 66% neurotomy of flexor hallucis longus, and 66% neurotomy of flexor digitorum longus in one case, because of associated claw toes and varus deformity).

Electrophysiology

All patients gave their informed consent for preoperative and postoperative recording of the H reflex, with ethical committee approval to the procedure according to the Declaration of Helsinki.

Recordings of Mmax and Hmax of the soleus muscle (and calculation of the Hmax/Mmax ratio) were performed preoperatively and postoperatively on day 1, 8 months, and 24 months according to the method described by Decq *et al.*³ Soleus appears to be predominantly involved in triceps spasticity.²¹ Therefore recordings did not include gastrocnemius muscles.

The recording was performed with the subject sitting, with the knee half flexed to 120° and the ankle flexed to 90° on the spastic side. Hmax and Mmax responses were obtained by bipolar stimulation of the tibial nerve, in the popliteal fossa, with surface electrodes pasted over the body of the soleus muscle.

Clinical follow up

The passive range of movement, the stretch reflex score, the repercussions on the knee, such as genu recurvatum, and motor control of dorsiflexion were evaluated after the operation.

Statistical analysis

Mmax responses, Hmax reflexes, and the Hmax/Mmax ratio of the affected side were compared preoperatively and postoperatively on day 1, 8 months, and 24 months by analysis of variance with repeated measures, and then by multiple two by two comparisons with Student-Newman-Keuls tests (GraphPad InStat version 3.00 for Windows 95, GraphPad Software, San Diego, CA, USA). Analysis was performed in patients for whom a complete recording was obtained (preoperative, postoperative on day 1, 8 months, and 24 months).

RESULTS

Follow up

No local or systemic complications were observed.

The mean (SD) postoperative follow up was 29 (13.5) months (range 10 to 48 months).

The Hmax reflex, Mmax response and determination of the Hmax/Mmax ratio were performed postoperatively, in all patients, on the day after the operation (day 1) and eight months after the operation; the recording at two years was performed in only five of six patients.

Course of spasticity

Stretch reflex

Clonus of the foot, with the knee flexed, resolved immediately postoperatively for all seven operated limbs. At the end of clinical follow up, it remained absent in six of seven limbs.

The stretch reflex with the knee extended immediately postoperatively was scored as 0 according to the Held-Tardieu scale in seven limbs. This normal stretch reflex (score 0) persisted at the end of follow up in four, but the exaggerated stretch reflex recurred in three limbs.

Improvement of equinus foot

Immediately postoperatively, all patients were able to place their heel on the ground. However, the second rocker of the ankle during the stance phase of gait was only restored in one patient. The equinus score therefore decreased from 2 to 1 in six patients and from 2 to 0 in one patient. Improvement of equinus score was maintained throughout follow up.

Figure 1 Electrophysiological data obtained for one patient. Illustrative case showing Hmax and Mmax recorded before surgery (A), one day after surgery (B), and two years after surgery (C). For each recording, the different traces represent the EMG obtained at increased electrical stimulation. The late response occurring at low stimulation intensity represents the M response while the earlier response occurring at higher stimulation intensity represents the M reflex. Compared with preoperative values, Hmax and Mmax are significantly reduced the day after surgery. Two years later, Hmax remains significantly reduced while Mmax amplitude is quite similar to the preoperative value.

Figure 2 In six legs, three items (Hmax amplitude, Mmax amplitude, and Hmax/Mmax ratio) were determined preoperatively and postoperatively at day one, eight months, and two years. The course of each item was statistically analysed by analysis of variance with repeated measures. When significant—meaning significant variation of this item among the four period of time—a post-test analysis was conducted comparing the postoperative values with the preoperative one using Student-Newman-Keuls test. A significant post-test analysis is noted by an asterisk in the figure. For each item, analysis of variance with repeated measures was significant (respectively $p=0.0015$ for Hmax/Mmax ratio, $p=0.0008$ for Hmax amplitude, and $p=0.015$ for Mmax amplitude). (A) Compared with mean preoperative value, Hmax/Mmax ratio was significantly lower in the three postoperative periods (Student-Newman-Keuls; test $p<0.01$ in each case). (B) Compared with mean preoperative value, Hmax amplitude was significantly lower in the three postoperative periods (Student-Newman-Keuls test; $p<0.01$ in each case). (C) Compared with mean preoperative value, Mmax amplitude was significantly lower at postoperative day one (Student-Newman-Keuls test; $p<0.01$); no significant reduction of Mmax amplitude was found at eight months or at two years postoperatively.

Improvement of passive range of ankle flexion

The preoperative passive range of ankle flexion with the knee extended was less than 5° in all limbs; it remained unchanged between 0° and 5° for five of seven operated ankles, and was improved in two cases, respectively increasing to more than 15° in one case and between 5° and 10° in the other.

Genu recurvatum and tibialis anterior motor control

Genu recurvatum, detected in three patients preoperatively, was only observed in two patients postoperatively.

Preoperatively, only two patients had motor control of dorsiflexion. This control was purely synkinetic. At the end of the study, five of the six patients had motor control of dorsiflexion. Three patients therefore had acquired tibialis anterior synkinetic motor control, one patient had acquired weak, but

non-synkinetic voluntary control and one patient had persistent synkinetic control.

Preoperative and postoperative comparison of electrophysiological parameters

Course of Hmax/Mmax (fig 1)

The mean Hmax/Mmax ratio was decreased by the operation in all patients. A statistically significant difference was observed between preoperative and day 1 postoperative mean values. However, the Hmax/Mmax ratio remained stable over time after the operation and the reduction of this ratio remained statistically significant two years after the operation (fig 2A).

Course of Hmax

The mean amplitude of the Hmax reflex decreased significantly between the preoperative assessment and the postoperative assessment on day 1. This reduction remained statistically significant two years after the operation (fig 2B).

Course of Mmax

The reduction of the amplitude of the Mmax response was statistically significant on postoperative day 1, but the value of Mmax eight months postoperatively was no longer significantly different from the preoperative value (fig 2C).

Reoperation

Two patients were considered to be insufficiently improved and were reoperated 26 months after the first operation.

One patient presented persistent clinical spasticity of the triceps surae. Two years after the first operation, this patient still had persistent equinus and moderate varus of the foot, as well as severe claw toes. Neurotomy of both gastrocnemius motor branches associated with neurotomy of flexor hallucis longus and flexor digitorum longus was performed, with complete resolution of equinovarus and claw toe deformities.

The second patient presented with bothersome claw toes two years after the tibial neurotomy.

This patient also had moderate persistent equinus, with a brisk Achilles tendon reflex, but an abolished triceps stretch reflex with the knee extended or flexed.

H reflex measurement at two years demonstrated an Hmax amplitude of 3.8 mV (compared with 0.1 mV at eight months) and an Hmax/Mmax ratio of 0.41 (compared with 0.02 at eight months).

Spastic equine was completely relieved by a motor block of the tibial nerve.

The objective of reoperation was therefore to reduce claw toes, combined with a procedure on the soleus in view of the increase of the H reflex.

Three months after operation, the patient no longer presented any equinus or claw toes and the triceps stretch reflex and Achilles tendon reflex were absent.

DISCUSSION

This study shows the prolonged efficacy of selective tibial neurotomy in the treatment of spastic equinus foot, both clinically, by reduction of equinus and reduction of the stretch reflex, and in terms of electrophysiological parameters, by reduction of the Hmax/Mmax ratio. It also emphasises the predominant role of the soleus in triceps surae spasticity.

Long term efficacy of neurotomy

The efficacy of selective neurotomy of the motor branches of the tibial nerve supplying the triceps surae, especially the soleus, in the treatment of equinus spastic foot has been previously reported.^{5 11 23}

The clinical results of this study show the long term efficacy of this treatment. At the end of follow up (two years), all patients presented a reduction of equinus and myoclonic triceps spasticity was relieved in five out of seven ankles.

In five ankles, fascicular resection of the superior nerve to soleus was sufficient to reduce spastic equinus foot, without recurrence, for a mean follow up of 28 months.

Respective roles of soleus and gastrocnemius muscles in spastic equinus foot

Spasticity of the triceps was improved in all patients, after one (four patients) or two operations (two patients).

Neurotomy involving only the motor branches of the soleus muscle was therefore effective in six of seven ankles (isolated superior nerve in five cases; superior and inferior nerve in one case); only one of six patients presented ankle spasticity partially related to the gastrocnemius muscles.

This confirms the results of previous studies concerning the predominant role of the soleus muscle in spastic equinus foot.^{11 21}

Absence of long term motor denervation

Significant motor denervation was observed immediately postoperatively after fascicular neurotomy of the superior nerve to soleus, characterised by reduction of the amplitude of the Mmax response. However, this parameter returned to its baseline value at eight months (fig 2C). Fascicular neurotomy therefore does not induce permanent denervation.

Peripheral neurotomy consists of partial section of the motor nerve of a muscle. This section therefore involves both sensory afferents, type Ia fibres and motor efferents, α motoneurons.

The Mmax motor response is correlated with the number of motor units—that is, the number of α motoneurons^{24–27} that are characterised by a defined number of nerve endings or motor end plates. The increase in the Mmax response with time can only be explained by mechanisms leading to reinnervation through an increase in the number of motor endplates—that is, sprouting.

Einsiedel demonstrated that this sprouting involved all residual α motoneurons after partial denervation in the rat.^{12 14}

Clinical trials, although less numerous, tend to demonstrate similar findings.^{28 29}

In our study, sprouting, as evaluated by return of the amplitude of the Mmax response to its baseline value, occurred at the latest eight months after the operation.

Significant reduction of the Hmax reflex and Hmax/Mmax ratio

The reduction of the Hmax/Mmax ratio and the amplitude of the Hmax reflex after selective neurotomy has already been reported.⁵

In our study, more than eight months after the operation, the amplitude of the Hmax reflex remained significantly decreased, while the M response was no longer significantly different from the preoperative value.

Reinnervation of muscle spindles was observed after nerve section.^{30 31} However, this non-specific reinnervation of muscle receptors was generally not functional.³²

In our study, although motor reinnervation occurred, partial interruption of the monosynaptic reflex arc persists in the long term, reflecting a permanent damage on the afferent side of the reflex arc or a decrease in the central transmission from Ia afferents to A motoneurons.

The two cases of reoperation

The two cases of reoperation cannot be strictly considered to be a recurrence, but rather reflect incomplete efficacy of the first operation, as these two patients had persistent ankle spasticity in the immediate postoperative period.

Correlation between spasticity and Hmax/Mmax ratio

In contrast with the findings reported by Berard *et al* in a paediatric population, motor reinnervation is probably not

responsible for recurrence of spasticity.³³ Return of excessive tone after neurotomy is concomitant with motoneuron reinnervation, but this hypertonia is probably not attributable to residual spasticity, defined as an exaggerated myotatic reflex, as this reflex is abolished in the long term (as shown in our study). Other central and peripheral mechanisms (including the muscles themselves) can probably explain the residual hypertonia observed, especially in children. In our series, the amplitude of the Mmax response was significantly increased in all patients postoperatively, but only the patient with an increase of the amplitude of Hmax and the Hmax/Mmax ratio presented residual spasticity of the soleus.

In conclusion, selective neurotomy of the motor branches of the tibial nerve supplying the triceps surae muscle is an effective treatment for spastic equinus foot, ensuring long term efficacy. It leads to a prolonged reduction of the Hmax/Mmax ratio. Neurotomy confined to fibres supplying the soleus muscle is sufficient in most cases.

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