Surg Radiol Anat (2002) 24: 91–96
DOI 10.1007/s00276-002-0022-9

ANATOMIC BASES OF MEDICAL, RADIOLOGICAL AND SURGICAL TECHNIQUES

B. Parratte · L. Tatu · F. Vuillier · M. Diop
G. Monnier

Intramuscular distribution of nerves in the human triceps surae muscle: anatomical bases for treatment of spastic drop foot with botulinum toxin

Received: 16 September 2001 / Accepted: 27 January 2002 / Published online: 7 June 2002

Abstract Recent progress has been made in selective functional treatment of hypertonia of spastic origin by local injection of botulinum toxin into the muscles responsible for equinus foot dynamic deformation. The technical aspect of the intervention requires a strategy adapted to the individual patient. Good practice is founded on precise knowledge of the intramuscular nerve distribution of end plate zones, since the target organ of the toxin is the motor end plate. Knowledge about the location of motor end plates, which differs according to the structure of the muscle in question, remains rather poor. Through macroscopic and stereoscopic microscopic dissection of the nerve courses in the triceps surae muscular group in 40 legs, we have ascertained in more detail the distribution of motor end plates, which appear to be more numerous in certain zones of the muscle bellies. These zones were measured morphometrically and divided into segments which are expressed in percentages of a standard leg length. We maintain that these zones are the injection sites most likely to guarantee the best treatment efficacy.

Innervation intramusculaire du triceps sural. Bases anatomiques du traitement du pied équin spastique par la toxine botulique

Résumé Le traitement sélectif fonctionnel de l'hypertonie d'origine spastique, par infiltrations locales de toxine botulique dans les muscles responsables de l'attitude vicieuse du pied en équin, constitue une avancée récente. L'aspect technique du geste intervient en aval de l'indication et de la stratégie adaptées pour un patient donné. Une bonne pratique repose sur une connaissance précise de l'innervation intramusculaire terminale, puisque l'organe cible de la toxine est représenté par la plaque neuromusculaire. Or cette localisation des plaques motrices dépend de la structure du muscle considéré et reste encore actuellement très mal connue. La dissection macroscopique, puis semi-microscopique, des trajets nerveux au sein de l'ensemble musculaire du triceps sural de 40 membres inférieurs nous a permis de déterminer la distribution "approchée" des terminaisons, qui apparaissent comme plus nombreuses dans certaines zones des corps musculaires. Ces zones ont été délimitées en segments qui, rapportés à une longueur moyenne de jambe et exprimés en pourcentage de cette longueur, constituent pour nous les sites d'injection susceptibles de garantir la meilleure efficacité.

Keywords Spasticity · Dynamic equinus foot · Botulinum toxin · Gastrocnemius muscle · Soleus muscle · Tibial nerve · Intramuscular nerve distribution

Introduction

Botulinum toxin is one of the most powerful toxins known. It blocks the presynaptic release of acetylcholine at the neuromuscular junction, causing weakness or paralysis of the injected muscles. The neuromuscular blockade it produces is irreversible, but recovery occurs over about 3 months by resprouting of the axons and formation of new acetylcholine receptors.

The clinical use of local injections of type A botulinum toxin is relatively recent, the concept of using minute dosages of this chemical agent in individual muscles having been developed by Scott in 1980 [9] to treat infant strabismus. For several years it has been a well-established form of symptomatic treatment in patients with hemifacial spasm, cervical or cranial dystonias and related disorders, but its therapeutic scope has continued to widen. As well as being used for other diseases associated with inappropriate muscular contractions or spasms, its use is now also proposed in treatment of limb

B. Parratte (✉) · L. Tatu · F. Vuillier · M. Diop · G. Monnier
Laboratoire d'Anatomie, Faculté de Médecine,
Place St Jacques, 25030 Besançon cedex, France
E-mail: bernard.parratte@univ-fcomte.fr
Tel.: +33-3-81665619
Fax: +33-3-81665676

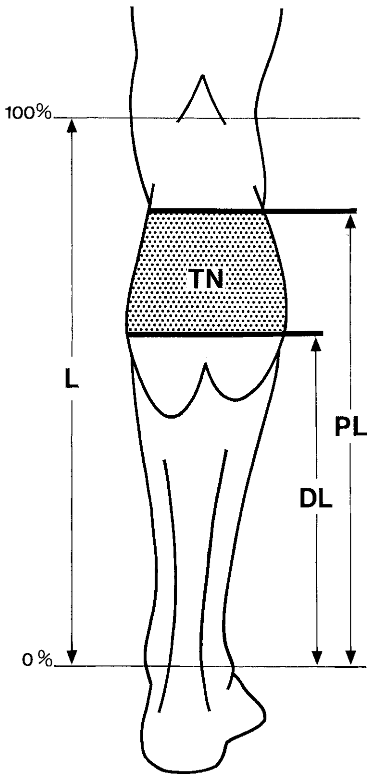

Fig. 1. On the length *L* of the leg measured from the top of the medial malleolus up to the proximal margin of the medial tibial condyle. *DL*, distal limit; *PL*, proximal limit of the area *TN*, where the terminal nerve ramifications were densest

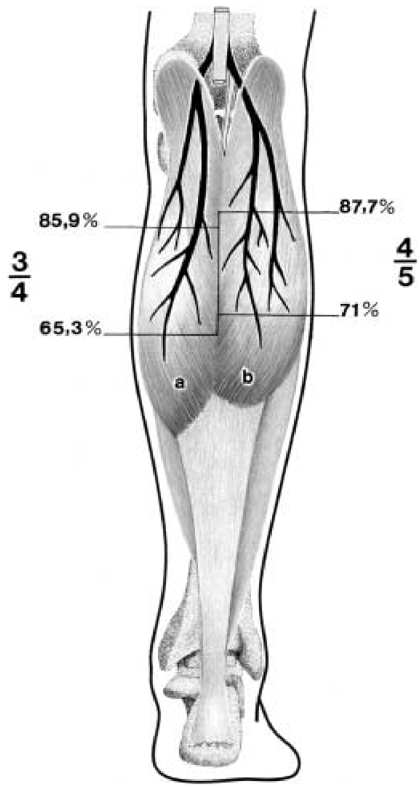

Fig. 2. Schematic drawing of the intramuscular nerve distribution inside the gastrocnemius. *a*, medial head; *b*, lateral head. Proximal and distal boundaries of the area where the terminal nerve ramifications are the densest are indicated in percentages of the mean length of the leg. The ratios 3/4 and 4/5 give the injection level considered optimal for the medial and lateral heads respectively

spasticity, following the demonstration that it safely reduces muscle tone and increases range of motion in these patients without causing significant side effects. Paralysis after toxin exposure is dose-dependent and we believe, as do others [12], that the toxin should be injected as close as possible to the end plate zones, because they are the target area of the molecule.

Therefore, the aim of this study was to specify where the motor nerves penetrate and arborize inside the gastrocnemius and soleus, whose hypertonic state is responsible for the equinus deformation of the spastic foot. In this way we hope to be able to minimize doses and to achieve the highest rate of selective muscular weakness, reducing the immediate risk of local diffusion, or systemic diffusion which could cause temporary generalized weakness; and later attenuating the risk of antibody formation which could lead to inefficiency of the toxin over repeated injections. The use of small dosages would at the same time decrease the cost of this rather expensive product.

Material and methods

On a total of 40 legs from embalmed adult human cadavers, dissection, firstly macroscopic and secondly under a stereoscopic microscope, was performed on nerves supplying gastrocnemius ($n=36$) and soleus ($n=37$). The nerves were dissected from proximal to distal, noting their number and origin until they penetrated into the muscle belly. Next we traced the intramuscular course of the main branches, and the patterns of their terminal arborizations were drawn until it was no longer possible to follow them. For each muscle, the layout of these terminal ramifications was determined first. Measurements were made along the length of the leg from the medial malleolus up to the proximal margin of the medial tibial condyle. Distances were expressed with reference to the top of the medial malleolus (Fig. 1) and were delimited as: the distance DL from the medial malleolus up to where the most distal terminal nerves were observed, and the distance PL from the medial malleolus up to the proximal ramifications. These assessments were then translated into percentages in relation to the length of the leg,

Table 1. Layout along the leg of terminal nerve arborizations (*PL*, proximal limit; *DL*, distal limit of the area where the terminal ramifications were the densest). Mean leg length was 35.1 cm (100%)

	Medial head of gastrocnemius		Lateral head of gastrocnemius		Soleus posterior nerve		Soleus anterior nerve	
	cm	%	cm	%	cm	%	cm	%
PL	30.1	85.9	30.8	87.7	26.8	76.5	22.9	64.8
DL	23.0	65.3	24.9	71.0	19.5	55.6	18.3	52.3

and finally the mean values were calculated. Comparing these values with the mean length of the leg, we achieved proximal and distal ratios corresponding to the maximum and minimum height of the muscle belly where the terminal nerve ramifications were the densest.

Results

Gastrocnemius muscle

From the tibial n. in the popliteal fossa, there were always two supply nerves, one for each head, arising either separately or as a common trunk. Each main supply nerve was firstly extramuscular, where it was joined by a vascular pedicle, then entered the axial border of the head and divided into two or three branches, exceptionally four, since this distribution was observed only twice in 36 cases; it supplied the lateral head. Table 1 summarizes these findings and Fig. 2 shows the terminal arborizations.

Soleus muscle

In spite of the great morphological variations in the architecture of this muscle, we always found a double nerve supply: one posterior and one anterior branch.

The posterior nerve supply arose from the tibial n. in the popliteal fossa, often in conjunction with the nerve

Fig. 3. Posterior view of an isolated left soleus after the gastrocnemius has been removed, leaving the lower part of the medial head (*1*). The intramuscular course of the posterior nerve (*2*) has been exposed, which divides into two branches here: lateral (*3*) and medial (*4*). Each one gives off several terminal arborizations (*arrowheads*)

to the lateral head of the gastrocnemius (26/37). It divided into two or three branches, before or when reaching the tendinous arch of the soleus. Each branch most often ran vertically, supplying the two medial and lateral parts of the muscle by giving off six to eight arborizations (Fig. 3).

The anterior nerve (Fig. 4) supply was always found, though often small, arising from the tibial n. immediately below the fibrous arch of the soleus, either independently or as part of a common trunk with other nerves to the deep muscles of the leg, which are the tibialis posterior, the flexor digitorum longus and the flexor hallucis longus. It entered the deep surface of the upper part of the muscle after a short course, and either rapidly ended in several branches distributing the anterior part, or divided into two branches that gave off arborizations to each half of the deep bipenniform part of the muscle. Table 1 emphasizes the data concerning the proximal and distal terminal arborizations. The delimited areas in Fig. 5 indicate the posterior and anterior supply nerves respectively.

Discussion

Selective functional treatment of focal limb dystonias by local injection of botulinum toxin is an important recent therapeutic advance. Injection efficiency depends on precise knowledge of intramuscular nerve supply, as the end plate zones are the target area of the toxin. The extramuscular courses of nerves are described in most

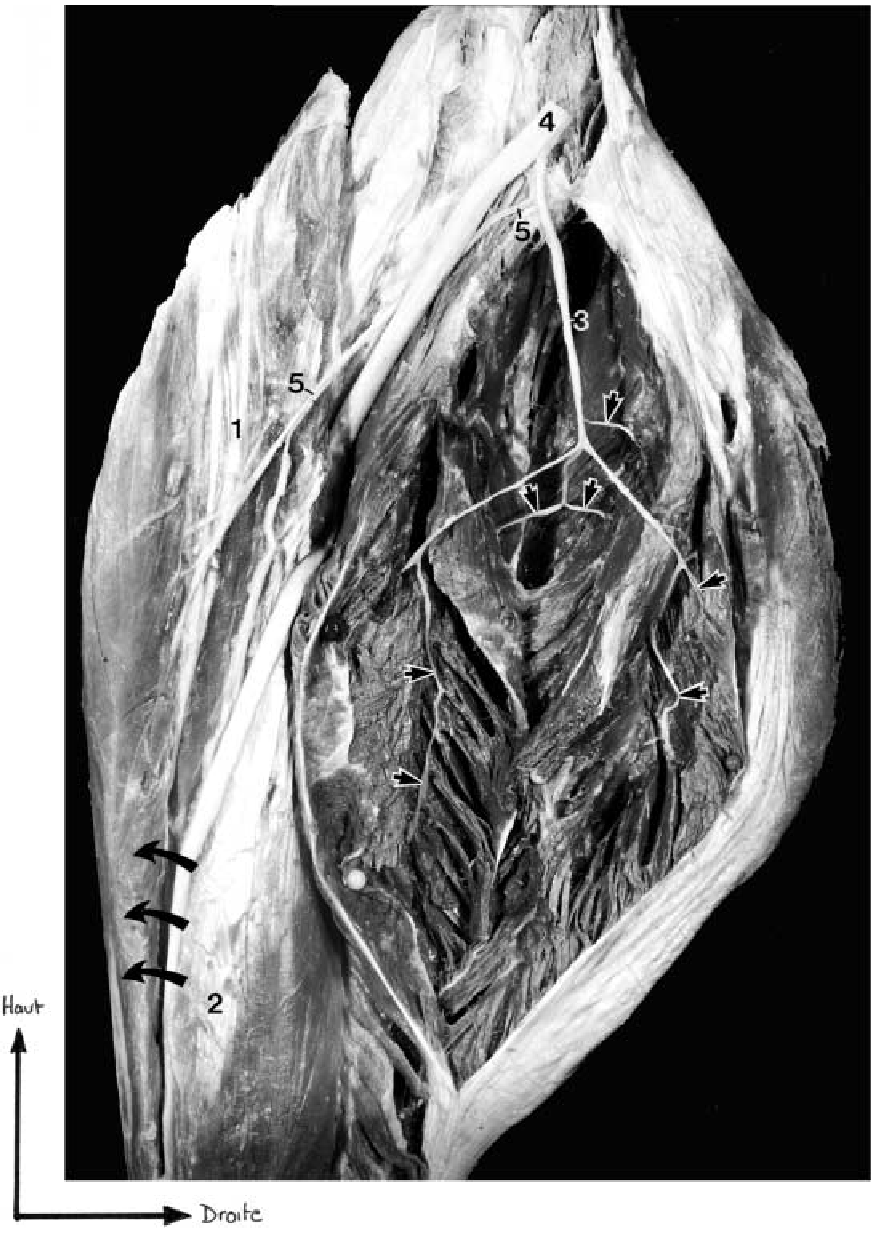

Fig. 4. Total attachment of the soleus showing the anterior view and the deep muscle layer of the leg which is turned over (*arrows*): *1*, tibialis posterior; *2*, flexor hallucis longus. Dissection of the anterior nerve of the soleus (*3*) which arises from the tibial nerve (*4*) in a common trunk with the tibialis posterior muscle nerve (*5*). Terminal intramuscular ramifications of the anterior nerve of the soleus (*arrowheads*)

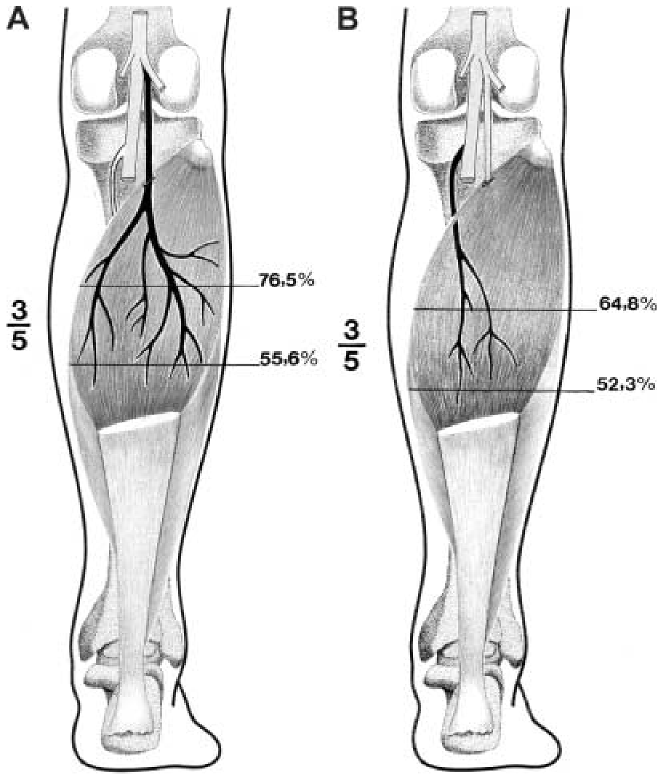

Fig. 5A, B. Schematic drawing of the intramuscular nerve distribution inside the soleus. **A** Posterior nerve. **B** Anterior nerve. Proximal and distal boundaries of the area where the terminal nerve ramifications are the densest are indicated as percentages of the mean length of the leg. The ratio 3/5 gives the injection level considered optimal

anatomy textbooks; however, only a few studies of intramuscular nerve supply have been done and they remain incomplete. The atlas by Brash [2] presents an interesting synthesis of the "neuro-vascular hila of limb muscles" without going further into the muscle bellies.

As a general rule, it is accepted that the motor end plates are equidistant from the poles of their respective muscle fibers [8]. They are grouped together into "terminal supply bands" [4] whose topography depends directly on the muscle structure, which is itself conditioned by how the muscle fibers are organized. Thus, there are: (1) semi-penniform muscles with short or long parallel fibers in which the topography of the motor end plate distribution zone is a straight line; (2) muscles with converging fibers, called penniform, and (3) muscles architecturally complex in which the motor end plate distribution zone is a sinuous line. Giving three examples of differently structured muscles, Aquilonius et al. [1] have illustrated the variability of the motor end plate zones from one muscle to another.

For the gastrocnemius, English and Letbetter [5] studied the structure of the lateral head and demonstrated that, despite extensive variations in muscle architecture, it is always compartmentalized around a nerve branch. This partitioning was emphasized in man by Wolf and Kim [13] as well, but only for the medial head of the gastrocnemius, and by Segal et al. [10]; nevertheless, these articles give more data and put forward more morphofunctional hypotheses than they give topographical information about intramuscular nerve supply.

For the soleus, the two reference studies are those by Schultz et al. [7] and, especially, Sekiya [11]. The first group described the intramuscular distribution of the posterior nerve, most often in three branches which give off numerous ramifications. They emphasize the frequent variations but give no details about how the majority of the end plates are distributed along the length of the leg. Nevertheless, as we observed also, they found that the anterior part nerve supply tends to extend distally. Sekiya described the double muscle nerve supply, posterior and anterior, with their interpenetrations. He emphasized the uniqueness of the nerve supply in man and primates, because of the existence of a bipenniform portion in the anterior of the muscle belly due to upright stance.

Thus, the objective of this study was to map out the intramuscular motor end plate zones of the gastrocnemius and the soleus, while recognizing that because of individual variations the precise description of the nerve supply is secondary to more general observations aimed at improving clinical practice. In the same way, only a general location has been determined, which does not permit an estimation of the density of the motor end plates in the area concerned, as their total number varies considerably according to the muscle: 430 in the medial head of the gastrocnemius, 250 in the soleus, according to Christensen [3], for a muscle belly which is much larger but functionally different. Our dissections, as fine as possible, have therefore allowed us to determine, for each muscle usually targeted in the treatment of spastic drop foot, the proximal and distal limits of the territories where the most nerve endings are observed. Taking into account the fact that the more composite the muscle, the more heterogeneous its supply, and that from a practical point of view we have tried to limit the number of needle insertion points for obvious reasons of patient comfort, we believe we are able to suggest optimal injection sites. These points are approximately located as follows (Figs. 2, 5):

- 3/4 of the way up the leg for the medial head of the gastrocnemius (PL 85.9%, DL 65.3%, mean of the delimited segment 75.6%) (Fig. 2);
- 4/5 of the way up the leg for the lateral head of the gastrocnemius (PL 87.7%, DL 71%, mean 79.4%) (Fig. 2);
- 3/5 for the soleus in two sites, lateral and medial, and at several postero-anterior levels (posterior nerve: PL 75.6%, DL 55.6%, mean 66.1% (Fig. 5A); anterior nerve: PL 64.8%, DL 52.3%, mean 58.6% (Fig. 5B)).

We believe these injection sites to be the zones most likely to guarantee maximum efficiency, taking into account that we can expect intramuscular diffusion of the toxin, which is theoretically possible over an area 5 cm in diameter around the needle were it not for the presence of the numerous fibrous compartments that characterize the superficial muscle layer of the calf.

While the hypertonic state of gastrocnemius and soleus is the cause of the equinovarus foot deformation, the spasticity also very frequently concerns the deep muscles of the calf: the tibialis posterior which, by adding its inversion factor, is responsible for the varus position; the flexor digitorum longus and the flexor hallucis longus, which are responsible for the permanent deformation or the dynamic onset of plantarflexion of the toes. Standardized injection of these deep layer muscles must be done taking into account the specific approach determined by their accessibility as well as their intramuscular nerve supply. We are already doing this, using a technique based on identical studies to those described above, which will be the subject of a future report.

References

1. Aquilonius SM, Askmark H, Gillberg PG, Nandedkar S, Olsson Y, Stälberg E (1984) Topographical localization of motor endplates in cryosections of whole human muscles. Muscle Nerve 7:287–293
2. Brash JC (1955) Neuro-vascular hila of limb muscles. E & S Livingstone, Edinburgh
3. Christensen E (1959) Topography of terminal motor innervation in striated muscles from stillborn infants. Am J Phys Med 38:65–78
4. Coers C (1953) Contribution à l'étude de la jonction neuromusculaire. II. Topographie zonale de l'innervation motrice terminale dans les muscles striés. Arch Biol (Liège) 64:495–505
5. English AW, Letbetter WD (1982) Anatomy and innervation of cat lateral gastrocnemius and plantaris muscles. Am J Anat 164:67–77
6. Monnier G, Parratte B, Tatu L, Vuillier F (2000) Management of the equinovarus deformity of the spastic foot with botulinum toxin. Practical aspects. Cinetec (CD-ROM)
7. Schultz M, Himstedt HW, Schumacher GH, Menning A, Freund E (1973) Zur Topographie der muskulären Nervenausbreitungen. 3. Untere Extremität. M. Soleus. Anat Anz 133:341–349
8. Schwarzacher von HG (1957) Zur Lage der motorischen Endplatten in den Skelettmuskeln. Acta Anat 30:758–774
9. Scott AB (1980) Botulinum toxin injection into extraocular muscles as an alternative to strabismus surgery. Ophthalmology 87:1044–1049
10. Segal RL, Wolf SL, De Camp MJ, Chopp MT, English AW (1991) Anatomical partitioning of three multiarticular human muscles. Acta Anat 142:261–266
11. Sekiya S (1991) Muscle architecture and intramuscular distribution of nerves in the human soleus muscle. Acta Anat 140:213–223
12. Shaari CM, Sanders I (1993) Quantifying how location and dose of botulinum toxin injections affect muscle paralysis. Muscle Nerve 16:964–969
13. Wolf SL, Kim JH (1997) Morphological analysis of the human tibialis anterior and medial gastrocnemius muscles. Acta Anat 158:287–295