

# Intramuscular Neural Distribution of the Sartorius Muscles: Treating Spasticity With Botulinum Neurotoxin

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## Research Article

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# Abstract

This study aimed to detect the idyllic locations for botulinum neurotoxin injection by analyzing the intramuscular neural distributions of the sartorius muscles. A altered Sihler's staining was conducted on sartorius muscles (15 specimens). The nerve entry points and intramuscular arborization areas were measured as a percentage of the total distance from the most prominent point of the anterior superior iliac spine (0%) to the medial femoral epicondyle (100%). Intramuscular neural distribution were densely detected at 20–40% and 60–80% for the sartorius muscles. The result suggests that the treatment of sartorius muscle spasticity requires botulinum neurotoxin injections in particular locations. These locations, corresponding to the locations of maximum arborization, are suggested as the most safest and effective points for botulinum neurotoxin injection.

## Introduction

Spasticity is a main contributor to functional loss in patients with impaired central nervous system, such as in stroke, cerebral palsy, multiple sclerosis, traumatic brain injury, spinal cord injury, and others <sup>1</sup>. Sartorius muscle, as a hip and knee flexor, is one of the commonly involved muscles, and long-lasting spasticity of the muscle results in abnormalities secondary to muscle hyperactivity, affecting lower levels of functions, such as impairment of gait. For ambulatory patients, hip and knee flexor spasticity results in crouched gait, which needs much more strength than in people with normal hip and knee extension. Since hip and knee flexor spasticity occurs in conjunction, surgical and medical treatments are required in sartorius muscle to improve the posture.

Presently, botulinum neurotoxin (BoNT) injection is among the most secure and effective approaches for relieving spasticity <sup>2–6</sup>. Since its consequences depend on the amount, the recommended BoNT levels should be sufficient in sartorius muscle at the area of neuromuscular junctions <sup>7</sup>. However, BoNT overdose may cause the neurotoxin to spread to adjacent muscles and cause undesirable paralysis <sup>8–10</sup>. Thus, in order to lessen the adverse effects and to maximize its clinical efficacy, BoNT must be injected near the neural arborized areas. Numerous studies have revealed the anatomical location of neuromuscular junctional areas of many different muscles <sup>10–14</sup>. The consequence of neural arborized area-targeted injection, in which most neuromuscular junctions are located, has been established in clinical studies on biceps brachii and psoas major muscles <sup>15,16</sup>. Intramuscular injection in neural arborized areas of biceps brachii and psoas major resulted in a much higher volume reduction than the control <sup>15,16</sup>.

Studies that explain BoNT injection locations by navigating intramuscular neural distribution with naked eye dissection have limits, such as perceiving minuscule nerves and the likelihood of neural damage <sup>17–26</sup>. Moreover, earlier studies have pronounced trouble in precisely detecting the tiny nerves <sup>14,27,28</sup>. These restrictions can be disregarded when proceeding with Sihler's staining, which is a whole-mount nerve staining that changes the muscle translucent while stained nerves.

Sihler's staining is an efficient method to precisely demonstrate the intramuscular nerve distribution without damaging the nerve itself, and offers a discrete and comprehensive outline of the nerve distribution.

The objective of this study was to determine the intramuscular nerve distribution of sartorius muscle using Sihler's staining and to suggest BoNT injection points for treating hip and knee flexor spasticity.

## Results

### Location of Nerve Entry Points

In all cases, the sartorius muscle was innervated by the femoral nerve. The mean entry point of the motor nerve penetrating the muscle was 1 to 3. Four cases had three nerve entry points, nine cases had two nerve entry points, and two cases had one nerve entry point. The distance of all nerve entry points was located at 10–30% from the anterior superior iliac spine (0%) to the medial femoral epicondyle (100%).

### Intramuscular Arborization Patterns

Eleven out of 15 sartorius muscles had the most nerve arborizations appear at two regions, located at proximal 20–40% and distal 60–80%. Three had most nerve arborization at proximal 30–40% and distal 60–80%, and one had it at proximal 30–40% and distal 60–70%. All specimens had the most distally located intramuscular nerve ending at around 80–90% of each muscle (Fig. 1).

## Discussion

The sartorius muscle, the longest muscle in the human anatomy, running over both hip and knee joints. It is a superficially and anteriorly located muscle of the thigh and diagonally runs from the anterior superior iliac spine to the medial side of the proximal tibia at the pes anserine. The insertion of the sartorius muscle is the superior medial part of the tibial bone, close to the medial tibial tubercle. The conjoint tendon of gracilis, semitendinosus, and sartorius muscles is known as the pes anserinus<sup>29</sup>. The sartorius muscle is innervated by the femoral nerve, provided by the nerve roots L2 to L4<sup>29</sup>. The nerve entry point, where the nerve pierces the muscle, was at its proximal end.

The most prevalent spasticity patterns in the lower extremities are hip flexion and adduction, knee flexion, equinovarus foot, and big toe hyperextension that impedes the gait of affected patients<sup>30</sup>. Since the sartorius is the only hip and knee flexor muscle, it is commonly targeted for BoNT injections to ease spasticity. BoNT injection in the sartorius muscle is not only for spasticity treatment, as many studies have performed BoNT injection to effectively prevent muscle contractures in total hip and knee arthroplasties and other surgeries<sup>31,32</sup>. Awaad et al. reported the functional contribution of BoNT injection into the sartorius muscle in the treatment of postoperative stiff hips.<sup>33</sup> Hamdy et al.<sup>34,35</sup> used BoNT in femoral lengthening surgery and concluded that it improved the post-operative pain reduction. On the contrary, Park et al.<sup>36</sup> reported that BoNT had no significant impact on pain reduction after

lengthening osteotomy. However, their study had the limitation of using smaller doses than Hamdy et al. and had targeted only the proximal part of the sartorius muscles with no clear injection points.

Moreover, the sartorius muscle is a superficially located muscle that is highly suitable for many applications in free muscle transfer and local transposition in the field of reconstructive plastic surgery. However, it was less used than the other flaps due to the lack of anatomical studies on its intramuscular neurovascular distribution<sup>29</sup>. Obeid et al. assessed 170 patients who underwent sartorius muscle flap for treating groin wounds, and reported that sartorius muscle flaps had low perioperative reintervention rate but had high complication rate<sup>37</sup>. The neurovascular anatomy is credible, and surgical delay could expand the neural supply and extend the arc of rotation of the local flap<sup>29</sup>.

The major therapeutic effects of BoNT are by impeding muscle contractions at the neuromuscular junction and cutting off the vicious cycle of pain<sup>38-40</sup>. However, there is still a risk of damaging the nerve trunks when BoNT was not injected into the neural arborized area, even if it is minimally invasive compared to surgical procedures. Likewise, substantial BoNT injections have resulted in the formation of antibodies which lowers its effectiveness<sup>8-10</sup>. Consequently, to increase the effectiveness and reduce the negative effects, a smaller amount of BoNT needs to be injected directly into the neural arborized areas, where most neuromuscular junctions are assumed to be located. Its efficacy was recognized in a clinical study on psoas major and biceps brachii muscles<sup>15,16</sup>. Intramuscular neural arborized area-targeted injection in these studies resulted in a higher reduction in muscle volume than conventional injection methods<sup>15,16</sup>.

Currently, there is no standardized injection point for BoNT treatment of the sartorius muscle. The amount of BoNT should be adequate to introduce a sufficient toxin level in the arborized area of neural distribution. This study used the Sihler's staining method, which provides a possible solution to resolve the limitations of manual dissection. The application of Sihler's staining to sartorius muscle will facilitate accurate and thorough understanding of the neural distribution. This study performed Sihler's staining to reveal the intramuscular neural distribution of the sartorius muscle in order to determine the most effective and safest BoNT injection point, and guide neural distributions for sartorius flap surgery (Fig. 2).

## Methods

### Subjects

Informed consent and approval were obtained from the families of the cadavers before the dissections were performed. All cadavers used in this study were legally donated and approved from ethics committee of the Surgical Anatomy Education Center, Yonsei University College of Medicine (approval code 20 - 009; approval date: May 5th, 2020). Sixteen sartorius muscles from 10 cadavers (five women and five men with a mean age of 74.2 years; range, 63-84 years) were dissected to explore nerve entry points, and Sihler's staining was performed to detect intramuscular neural distribution.

The 16 sartorius muscles were harvested from 10 cadavers (five men and five women) and Sihler's staining was done<sup>41</sup>. This procedure requires multiple stages to acquire the image of the intramuscular neural distribution<sup>7,42-46</sup>. We conducted this procedure with some modifications. After the staining procedures, the sartorius muscles were equally divided into 10, each represented division of 10%, respectively to the total length. The origin of the sartorius muscles, nerve entry points, and intramuscular neural arborized locations were measured as percentages from the anterior superior iliac spine (0%) to the medial femoral epicondyle (100%) (Fig. 3).

The stages of the Sihler's staining of the sartorius muscle are described in Fig. 4.

## Modified Sihler's Staining

**Fixation stage:** The extracted sartorius muscles underwent fixation for 30 days in a container filled with 10% unneutralized formalin. The formalin solution was replaced each time it turned hazy.

**Maceration and depigmentation stages:** Once fixation was completed, the sartorius muscles were placed in flowing water for 1 h. Next, the sartorius muscles were positioned in a 3% aqueous potassium hydroxide solution with hydrogen peroxide for two weeks.

**Decalcification stage:** The macerated sartorius muscle was immersed in a container filled with Sihler's solution I, which is composed of glycerin, aqueous chloral hydrate, and glacial acetic acid, for three days.

**Staining stage:** Sufficiently decalcified sartorius muscles were later stained by placing them for a day in Sihler's solution II, composed of glycerin, acetic acid, and aqueous chloral hydrate.

**Destaining stage:** Stained sartorius muscles were immersed for 3 to 5 hours in Sihler's solution I once again for sartorius muscle tissue destaining. The immersion was terminated before the nerves were destained.

**Neutralization stage:** Destained sartorius muscle was prepared in flowing water for 30 min. Afterwards the muscles were immersed in 0.05% lithium carbonate solution for 30 min.

**Clearing stage:** Neutralized sartorius muscles were placed in containers with increasing level of glycerin concentration within five days. Throughout this procedure, the concentration level was progressively increased in 20% increments to 40–100%.

## Abbreviations

botulinum neurotoxin (BoNT), fixation (FX), maceration and depigmentation (MD), decalcification, staining (ST), and clearing (CL).

## Declarations

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## Author Contribution

KHY: research concept, study design, and writing of the manuscript

JHL: research concept and study design

KKS: literature review and data collection

HJK: reviewing/editing a draft of the manuscript, Supervise the manuscript

## Declarations

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## Conflicts of interest/Competing interests

The author(s) declare no competing interests.

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## Figures



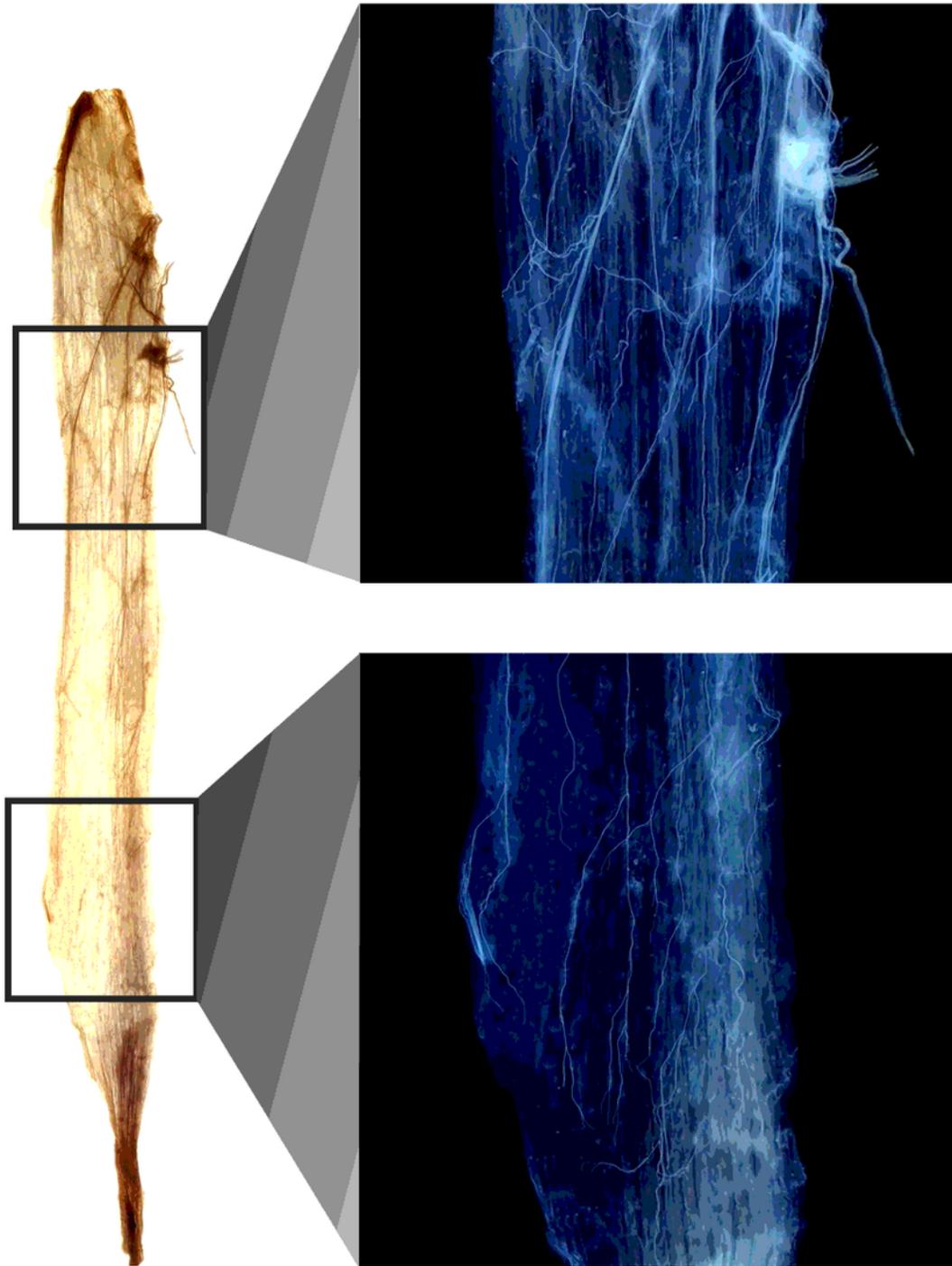
**Figure 1**

A Sihler's-stained sartorius muscle with enlarged images of intramuscular neural distributions. Intramuscular nerve pattern and entry points were revealed by dissection and staining.



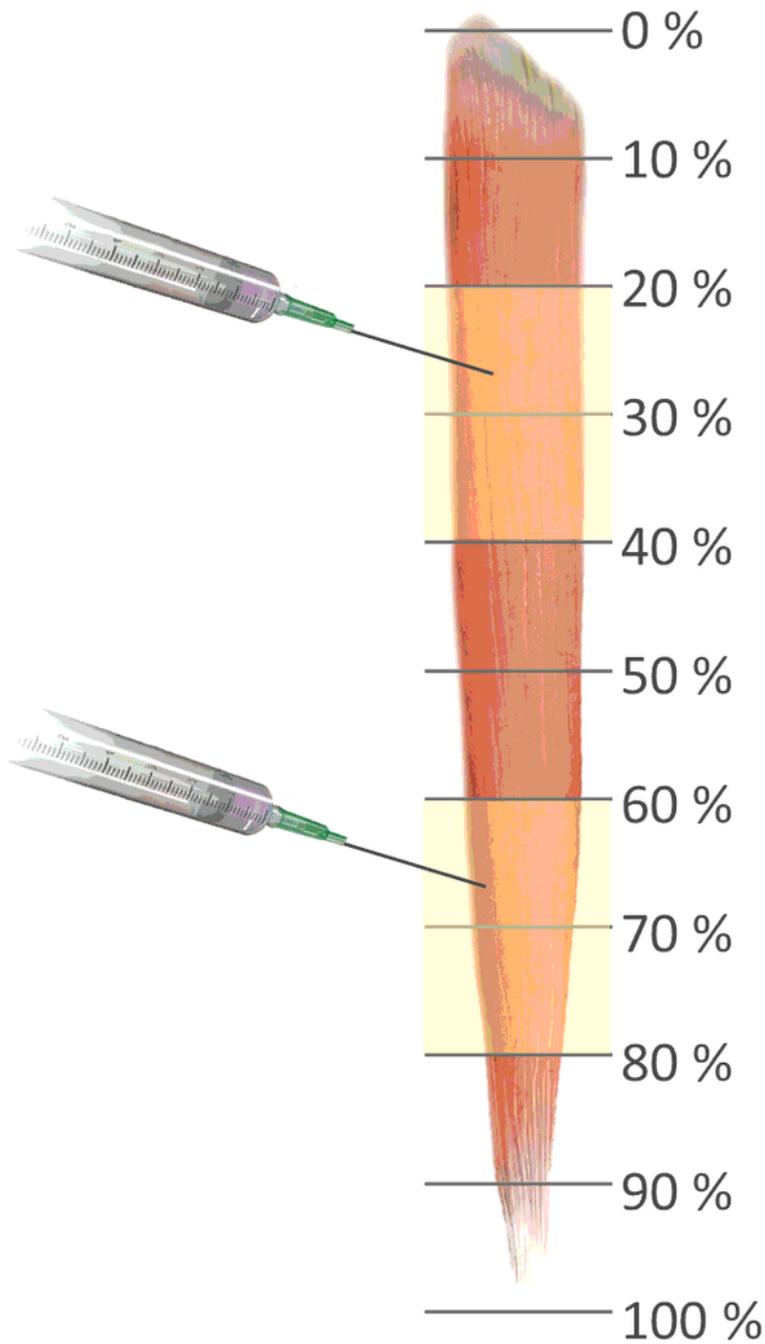
**Figure 2**

Recommendation for electromyography or BoNT injection of the sartorius muscle. The ultimate suggestions were achieved in relatively to the anterior superior iliac spine to the medial femoral epicondyle. The sartorius muscles demonstrated arborization neural distribution at 20–40% and 60–80% (yellow boxes).



**Figure 3**

Sartorius muscles were harvested from the anterior superior iliac spine (0%) to the medial femoral epicondyle (100%).



**Figure 4**

The sartorius muscle underwent modified Sihler's staining. The method consists of the procedures of fixation (FX), maceration and depigmentation (MD), decalcification, staining (ST), and clearing (CL).