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Localizing motor entry points of adductor muscles of thigh for motor point procedures in the treatment of adductor spasticity

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Abstract: Spasticity which is focal or segmental such as affecting a single muscle group or limb can be treated by chemical neurolysis or surgical denervation at the neurovascular hilus. This study determines the motor entry points (MEPs) of adductor muscles of the thigh in the adult Indian population and identifies precise anatomical landmarks for the successful performance motor point procedures for the relief of muscle spasticity. A total of 10 adult lower limbs were dissected, and nerve branches to adductor muscles were carefully exposed up to their MEP. The morphometry of adductor muscles, precise locations of proximal and distal MEPs, and ideal sites for motor point procedures were identified. The median number of MEPs in adductor longus was two. Most of them were located between 40% and 50% of the muscle length *i.e.*, in the third-fifth of the total muscle length. Adductor magnus and gracilis had a median number of one and six MEPs respectively. The ideal site of motor point procedures is in the second-fifth of the muscle length for both. This preliminary study describes the location of MEPs and ideal sites of motor point procedures in the adductor muscle of the thigh. However, further cadaveric and electromyographic studies with larger samples are necessary to investigate precise locations of MEPs aiding in the treatment of spasticity.

Key words: Motor end plate, Muscle spasticity, Botulinum toxin, Lower limb

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Introduction

Spasticity is defined as a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks as one of the components of the upper motor neuron syndrome. This is due to the reduced central inhibition to the hyperexcitability of the stretch reflex. Spasticity may accompany both diffuse or localized cerebral or spinal pathology and is a common sequelae of neuromuscular disability seen in conditions such as stroke, traumatic brain injury, spinal cord injury, cerebral palsy, and multiple sclerosis [1-3]. Functionally, spasticity can cause profound interference with activities of daily living, nursing care, personal hygiene and mobility, and can lead to the development of pressure sores, torsion of long bones, fractures, and contractures [1, 4].

Treatment for spasticity is often multidisciplinary with continuity of care between the hospital and the community

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rehabilitation team [4]. The treatment modalities for spasticity include: supportive treatments such as physiotherapy, nursing care, use of splints, body positioning; physical modalities like application of cold or heat therapy; use of pharmacologic agents and lastly surgical interventions [5]. Intramuscular injections with pharmacologic agents remain an effective choice, especially for treating focal spasticity with minimum systemic side-effects [6-9].

Spasticity which is focal or segmental such as affecting a single muscle group or limb can be treated by chemical neurolysis or surgical denervation. In chemical neurolysis, neural tissue innervating a muscle is destroyed by a chemical agent to give a long-lasting effect. Motor-point block is a classic example of chemical denervation where a chemical agent is injected intramuscularly to block a peripheral nerve as it enters the neuro-vascular hilus of the muscle, causing minimal systemic adverse effects [5, 6, 10]. The technique can be performed in an out-patient setting and shows immediate improvement. Once the spasticity is relieved, the physiotherapist can perform stretching exercises and movement pattern correction [11]. Commonly used agents include phenol, ethanol, and neurotoxins [3, 6, 11-14].

Neurotoxins such as the botulinum toxin inhibits the exocytosis of acetylcholine from the pre-synaptic terminals at the neuromuscular junction and is an extremely potent neuromuscular blocking agent when injected at the motor entry point (MEP) [6, 15]. It results in effective chemical denervation with significant reduction in muscle tone, relief from spasticity and improved range of motion, without undesirable generalized weakness [6]. The effect lasts for about 4 to 6 months [16]. Injection of botulinum toxin has been widely recognized as the most effective method for treatment of spasticity [17]. Since the toxin acts by uptake into the presynaptic membrane, it is important to inject the toxin into the portion of muscle where there is maximum concentration of neuromuscular junctions (motor end plates) [17-19]. In the clinical setting, there is a practical limitation to identify the intramuscular course of tiny nerve terminals with the naked eye. Hence, the approach commonly used in clinical practice is to identify the precise entry points of nerves into the neurovascular hilus of the spastic muscle for chemical neurolysis and surgical neurotomy [5, 20, 21]. The advantage of botulinum toxin is that it acts selectively on motor nerve terminals without affecting sensory nerves [10]. The effect of Botulinum toxin is dose dependent. Greater relief of spasticity is observed with a higher dose. Injecting higher doses of Botulinum toxin may have a higher chance of diffusion to surrounding tissues and may cause weakness of adjacent or non-targeted muscles groups leading to urinary incontinence, dysphagia and rarely death [16]. Formation of antibodies may have a neutralizing effect and attenuate the treatment efficacy [22, 23]. This can be overcome by injecting alternate serotypes of botulinum, intravenous immunoglobulins or plasmapheresis [24]. Injection of low doses of Botulinum toxin aimed precisely at or close to the MEP where neuromuscular arborization is maximal, would be ideal for achieving an optimum effect in decreasing spasticity with minimal adverse effects [2, 5, 20, 25].

Selective neurotomy is performed in cases that have shown resistance to chemical denervation. Selective motor neurotomy or fasciculotomy, is an invasive procedure in which the motor fascicles carrying excessive impulses are identified by stimulation and ablated at the MEP or neurovascular hilus of the affected muscle [26-30]. This causes permanent relief of excessive spasticity without affecting posture or balance, resulting in a remarkable increase in self-care activities and mobility [26, 27].

Common muscle groups involved in spasticity of the lower limb include the adductor group and the hamstring group of muscles of the thigh. There is no data that report on the position of MEPs in these muscle groups in the Indian population. This study determines the MEPs of adductor muscles of thigh and also identifies precise anatomical landmarks for the successful performance of interventional procedures such as motor point injection for chemical neurolysis and selective motor fasciculotomy for relief of spasticity.

Materials and Methods

The study was conducted after obtaining ethical approval from the Ethical Review Committee (Institutional Review Board) at Christian Medical College, Vellore (IRB minute no. 8889). The sample size was estimated based on data published by Woodley and Mercer (2005) [31]. Using the below formula, where standard deviation (SD) was 2.97 and precision (d) was 2.0 units, the required sample size was arrived at 9 lower limbs.

$$\text{Sample size, } (n)=(4\times SD^2)/d^2$$

The study was performed on 10 lower limbs from 5 formalin embalmed adult cadavers (4 male and 1 female)

belonging to the South Indian population, aged between 33 to 92 years of age donated to the anatomy department of Christian Medical College, Vellore under the voluntary body donation program. Under the body donation program informed consent was obtained from all donors and/or next to kin to utilize the body for teaching and research purposes. All experiments were performed in accordance with relevant guidelines and regulations, abiding by the Declaration of Helsinki, and was in line with the regulations of the institutional research and ethical committees. Lower limbs having malformation or flexion deformities were excluded from the study. Measurements were standardised by the investigators which included medical anatomists and a rehabilitative orthopaedic surgeon. Variables were measured using a sliding digital vernier calliper (ROBUST) with a resolution of 0.01 mm, a measuring tape and a metre scale.

Dissection

The cadaver was laid in a supine position with the hip, knee, and ankle joints in neutral position. Careful dissection of the adductor region was performed, and muscles and neurovascular bundles exposed. The nerve branches were carefully exposed up to the neurovascular hilus or MEP of the muscle. The MEPs of the following adductor muscles were studied: adductor longus, adductor magnus and gracilis. The intramuscular course of the nerves was not pursued. Adductor muscles were supplied by multiple nerve branches that entered the muscle often at more than one neurovascular hilus. The point at which each branch made an entry into the muscle, *i.e.,* the MEP was identified (Fig. 1). The highest entry point, where a proximal branch of the nerve entered the muscle, was described as the proximal entry point (PEP). The lowest point where a distal branch of the nerve entered the muscle was called the distal entry point (DEP). The position of the PEP and DEP was marked using colored pins. The distance of both the PEP and DEP from the origin of the muscle was measured using a measuring tape.

Measurement of variables

The variables measured were:

a) Length of the muscle (L)–measured along the long axis of the adductor muscles from the proximal attachment to the hip bone to its distal bony insertion.

b) Number of MEPs for each muscle.

c) Distance of the PEP from the origin of muscle–$D_{(o\text{-}PEP)}$.

d) Distance of the DEP from the origin of muscle–$D_{(o\text{-}DEP)}$.

e) Position of PEP from origin expressed as a percentage of length of muscle, calculated using the formula: PEP%=(PEP/L)×100.

f) Position of DEP from origin expressed as a percentage of length of muscle, calculated using the formula: DEP%=(DEP/L)×100.

g) Ideal site of MEP injection, $D_{(PEP\text{-}DEP)}$–defined as the region including and between the PEP and DEP, where all MEPs are located.

h) As described in (f), the ideal site of motor point injection was also expressed as a percentage of the length of the muscles, $D\%_{(PEP\text{-}DEP)}$.

Results

The baseline characteristics of the measured variables are shown in Table 1. The position of PEP, DEP and the ideal site of injection is shown in Table 2.

Among the adductor muscles, gracilis had the highest number of MEPs (median=6) whereas Adductor magnus had the lowest mean number of MEPs (median=1). Table 2 demonstrates the position of PEP and DEP and the ideal site for motor point procedures.

In the adductor group of muscles, both adductor magnus and gracilis had maximum number of MEPs in its second-fifths, whereas adductor longus had all its MEPs in the third-

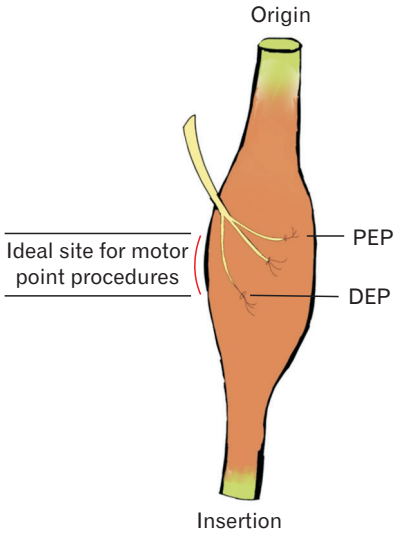

Fig. 1. Representative diagram showing three motor entry points in a muscle. The proximal entry point (PEP) and distal entry point (DEP) are labelled. Region between the PEP and DEP is the ideal site for motor point procedures.

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Table 1. Shows the measured variables for the adductor muscles

	Measured variables	Adductor longus	Adductor magnus	Gracilis
a	Length of muscle (cm)	22 (17.0–23.0)	34 (32.9–35.4)	41 (40–44.4)
b	Number of MEP	2.0 (2.0–3.0)	1.0 (1.0–3.2)	6 (3.8–8.2)
c	PEP from origin (cm)	8.8 (4.8–9.6)	10.5 (9.5–13.0)	12.0 (10.0-13.0)
d	DEP from origin (cm)	9.6 (9.5–11.5)	13 (6.3–15.0)	15.5 (14.0–16.6)
e	Location of PEP as % of L=PEP/L×100 (%)	39.3 (28.2–42.7)	31.2 (28.3–38.0)	28.8 (25.2–32.1)
f	Location of DEP as % of L=DEP/L×100 (%)	49.3 (44.8–55.9)	38.2 (19.4–41.1)	36.7 (34.1–40.1)

Values are presented as median (interquartile range). MEP, motor entry point; PEP, proximal entry point; DEP, distal entry point; L, length of the muscle.

Table 2. Position of proximal entry point and distal entry point as a percentage of muscle length

Name of muscle	PEP=(PEP/L)×100 (%)	DEP=(DEP/L)×100 (%)	Ideal site for motor point procedures
Adductor longus	40	50	In the third-fifth of the muscle length (or middle first-third).
Adductor magnus	31	38	In the second-fifth of the muscle length.
Gracilis	29	37	In the second-fifth of the muscle length.

PEP, proximal entry point; L, length of the muscle; DEP, distal entry point.

fifth of the muscle.

Discussion

Precise localization of the MEPs is essential for treatment of muscle spasticity especially during procedures such as neurotoxin injection and selective motor fasciculotomy [26, 27, 32, 33]. Neurotoxin acts pre-synaptically by blocking the release of acetylcholine resulting in reduced tone of the spastic muscles [6, 33]. Borodic et al. [34] in their study on albino rabbits observed that at lower doses of botulinum A toxin (1 IU), collapse of the diffusion gradient occurred over a 15–30 mm segment of muscle, whereas at higher doses of 5–10 IU, diffusion occurred across the entire muscle with no apparent end point. In muscles of the human lower limb which have considerable length, a small dose given precisely at regions of maximum concentration of MEPs would provide maximum benefit. Injection of larger doses at multiple sites along the length of the muscle would result in spread of the toxin to adjacent tissues and blood vessels resulting in systemic side effects [35]. Few studies have investigated intramuscular neural arborization and position of neuromuscular junctions using cholinesterase or Sihler's staining [2, 19, 36]. Though these studies have laboriously dissected miniscule intramuscular branches of nerves and concluded that maximum neuromuscular junctions and arborizations are located close to the PEP and DEP, due to the impracticality of replicating it in the real patient setting, most clinicians aim to identify entry points of motor nerves into muscles for chemical neurolysis [17, 19, 35]. Selective motor fasciculotomy is usually undertaken when the patient is resistant to chemical neurolysis and is more commonly done to relieve lower limb spasticity with lesser use in the upper limb [27, 37, 38].

Previously, there were misconceived notions that MEPs were located in the middle third of the muscle. But anatomical and electromyographic studies have reported that this is untrue and may vary between muscle groups [3]. There is scarcity of data regarding the number of MEPs of adductor muscles of thigh. Though a handful of studies have identified the location of MEPs in the adductor longus muscle, the bony landmarks used to measure distances are inconsistent and variable between the reports. This preliminary study has clearly elucidated that MEPs may cluster around fixed portions or lengths of adductor muscles of thigh.

Adductor longus

According to a study done by Won et al. [2] the region of maximum density of neuromuscular junctions in adductor longus muscle was at 35% of the length of the femur from anterior superior iliac spine. Childers [18], state that the MEPs of Adductor longus muscle of thigh is located at 26%±4.8% along a longitudinal axis drawn from the pubic tubercle to medial femoral condyle. Crystal et al. [38] report that the majority (75%) of adductor muscles had only one MEP and that the MEP of the adductor longus muscle was located at 31%±1.1% along a reference line from the symphysis pubis to the medial joint line at the distal extent of the medial femoral condyle. Though the location of MEP described by Crystal et al. [38] is slightly different from our study, it is noteworthy that the reference points used in both studies are different. We measured position of MEPs as a percentage of the length of the muscle from its origin at the pubic bone to is insertion

at the tibia or fibula, Crystal et al. [38] have measured it as a percentage from the symphysis pubis to the medial joint line. In our study, 80% of the adductor longus muscle had two MEPs and the rest had 6–8 MEPs. In our study, the PEP was located at 8.8 cm from the body of pubis, which was at 40% of the muscle length from its origin at the body of pubis to its insertion. The DEP was located at 9.6 cm from its origin, which is at 50% of the muscle length. The maximum number of MEPs was located within the third-fifths of the muscle along its length.

Adductor magnus

There is scarcity of data regarding the number of MEPs of adductor magnus. In a study done by Childers [18], the MEPs of adductor magnus were mostly located at 30.4%±4.1% along a longitudinal axis drawn from the pubic tubercle to medial femoral condyle. Crystal et al. [38] report that the adductor magnus had only one MEP and its mean location was at 38%±2.5% of a reference line from the symphysis pubis to the medial joint line at the distal extent of the medial femoral condyle. This compares very closely to the current study. In our study, the adductor magnus has a median number of only one MEP. We report that the PEP was located 10.5 cm from its origin at the body of pubis (*i.e.,* 31% of its muscle length). The DEP is located at 13 cm (*i.e.,* at 38% of muscle length). All MEPs of the adductor magnus were concentrated within 3.5 cm from the PEP which is within the second-fifth of the muscle length.

Gracilis

Again, there is scarcity of data regarding the number of MEPs of gracilis muscle. According to the study done by Won et al. [2] maximum density of neuromuscular junctions was found to be at 29.2%–33.5% along the length of gracilis. In a study done by Childers [18], the MEPs of gracilis was located at a point 32%±2% along a longitudinal axis drawn from the pubic tubercle to medial femoral condyle. Crystal et al. [38] report that most motor points of gracilis were located at 44%±3% of a reference line from the symphysis pubis to the medial joint line at the distal extent of the medial femoral condyle. In our study, the gracilis muscle had an average number of 6 motor points. In our study, the PEP was located at 12 cm from the origin of the muscle at the body of pubis (28.8% of muscle length). The DEP was located 15.5 cm (36.7% of muscle length). Hence, all MEPs were maximally concentrated within the second-fifth of the gracilis muscle along its length.

Comparison of ideal injection sites

A few studies have recommended ideal injection sites for botulinum toxin injection. However, these reports have each recommended varying methods based on different reference points as shown in Table 3 [35, 39, 40]. Fig. 2 demonstrates the ideal site for motor point procedures based on the current study. In the current study, the ideal sites for motor point procedures are shown as fractions or percentages along the long axis of the muscle from the point of bony origin to its distal insertion. Precise positions of MEPs can also be reconfirmed by electromyography prior to botulinum toxin injection.

The preliminary findings of this study must provoke larger studies to confirm the findings in the Indian population. Though this study focusses primarily on adductor muscles, further research on precise location of MEPs in other muscle groups of upper and lower limbs commonly involved in spasticity should be investigated.

Table 3. Shows a comparison of the optimum site for botulinum toxin injection

Muscle	Current study	Fheodoroff et al. [39]	Berweck and Heinen [40]	Van Campenhout and Molenaers [35]
Adductor longus	40% to 50% of muscle length (third-fifth of the muscle length)	Proximal first-third of thigh.	31% of the reference line joining pubic tubercle to medial femoral condyle.	Proximal third of the thigh.
Adductor magnus	31% to 38% of muscle length (second-fifth of muscle length)	In side-lying position, anterior and posterior to gracilis in middle third of thigh.	Point just distal to 38% of reference line joining pubic tubercle to medial femoral condyle.	In side-lying position, anterior and posterior to gracilis in middle third of thigh.
Gracilis	29% to 37% of muscle length (second-fifth of muscle length	Middle third of line joining pubic symphysis and pes anserinus.	Limit of proximal & middle third and middle & distal third of thigh.	Proximal third of line joining pubic symphysis and pes anserinus.

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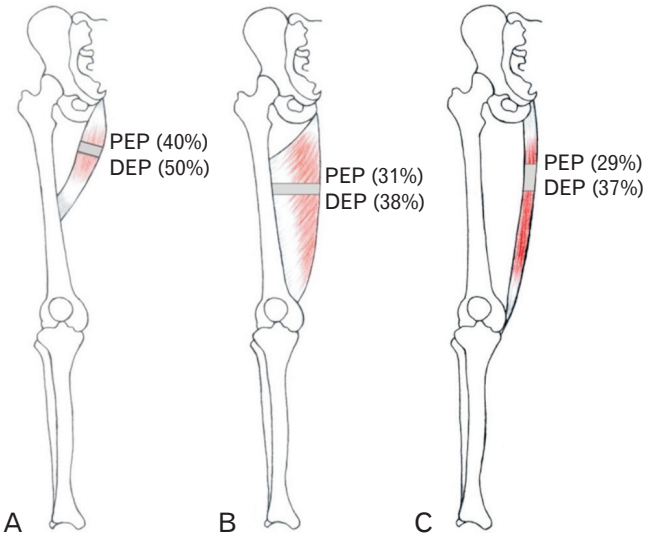

Fig. 2. Shows the ideal site for motor point procedures in the adductor muscles based on the current study (A) adductor longus (B) adductor magnus (C) gracilis. PEP, proximal entry point; DEP, distal entry point.

Limitations of study

This study has identified positions of MEPs in the South Indian adult population using cadaveric dissection and may not be fully representative of the population and the dynamic properties of living muscle tissue. In the future, further studies using real-time ultrasound and electromyography on spastic muscles of affected patients including children would be beneficial to enable a holistic approach to localize MEPs.

In conclusion, all adductor muscles are innervated from its deeper aspect. Among the adductor muscles, gracilis has the maximum number of MEPs (six) and adductor magnus the least (one). MEPs are maximally located within the third-fifth of the length of adductor longus, and within the second-fifth of adductor magnus and gracilis. These locations would be ideal sites for motor point procedures such as chemical neurolysis and selective motor fasciculotomy for relief of adductor muscle spasticity in neuromuscular disorders. Similar anatomic studies in other racial groups may need to be done to observe for variations if any. The preliminary findings of this research in the Indian population must be strengthened by larger studies using human cadavers and clinical electromyography to identify precise locations of MEPs for treatment of spasticity.

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Author Contributions

Conceptualization: IJP, AMA, SJH, HPM. Data acquisition: AMA, IJP. Data analysis or interpretation: IJP, AMA, JL, SJH, HPM. Drafting of the manuscript: IJP, AMA. Critical revision of the manuscript: IJP, AMA, JL, SJH. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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