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# Effects of Microselective Neurotomy on Focal Spasticity and Description of the Surgical Technique

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## Abstract

We studied the microselective neurotomy (MSN) and its advantages to alleviate disabling spasticity. The best indication for MSN is focal spasticity. We performed 298 MSN, 87 nerves on the upper limb, 211 nerves on the lower limb) in 68 patients. The initial causes were: stroke, cranial trauma, postoperative complications and multiple sclerosis. MSN procedures were performed on the median nerve (n = 40) for wrist and finger flexion; musculo-cutaneus nerve (n = 38) for elbow flexion; ulnaris nerve (n = 9) for cubital deviation of the hand; gastrocnemius nerve (n = 98) and soleus nerve (n = 49) for equinus foot, tibial posterior nerve (n = 45) for varus foot, and fascicles (or bundles) of the flexor digitorum for "claw" toes (n = 19). The main preoperative test to identify the responsible nerve was a neuromuscular block with local anesthesia (lidocaine or bupivacaine) injected into the site of the nerve connecting the spastic muscle. During surgery, the identified nerve was exposed and its epineurium opened. Nerve bundles were teased apart into individual rootlets and a number of rootlets cut were previously planned, according to the spasticity. Follow-up was performed for up to 10 years, with a mean period of 29 months. Results demonstrated a reduction of limb spasticity of 2 to 3 points: modified Ashworth scale (MAS). Pain and clonus were also diminished in the affected limb. In some cases, voluntary movement was once again possible. MSN is a useful alternative in those cases of focal spasticity where physiotherapy and nerve block with botulinum toxin or phenol no longer produce satisfactory results.

**Keywords**

Focal Spasticity, Microselective Neurotomy, Neurosurgery of Spasticity

## 1. Introduction

In a vast majority of plegic or paretic patients, spasticity worsens their ability to gain improvement from rehabilitation and physiotherapy and it is the cause of painful and abnormal postures. However, spasticity can be treated by several means: conservative approaches, such as pharmacotherapy, neuromuscular blocks with phenol or botulinum toxin [1] [2]; and invasive procedures, such as intrathecal infusion of baclofen/baclofen pump, dorsal selective radicellotomy, dorsal root entry zone (DREZ)-otomy, and microselective neurotomy (MSN) of the motor peripheral nerves which directly connect to the muscles whose spasticity needs to be alleviated. In this paper, we will discuss our experience with MSN in the treatment of focal spasticity.

Originally introduced by Stoffel, cited by Decq [3], the MSN technique was later improved by Gross [4] and finally popularized by Sindou [5] [6] [7] and reproduced by many others [8] [9] [10] [11]. The objective of this technique is to reduce motor innervation to spastic muscles by sectioning motor fascicles within the nerve, sparing sensory fascicles, all identified in open microsurgery. Other authors were able to further develop this technique into the procedure that we use currently [3] [12] [13]. The best indication for the use of MSN technique is focal spasticity, as in the hemiplegic patient. MSN can be applied in cases of spasticity where one limb is particularly more affected than the others. In fact, MSN has also further been indicated in children with cerebral palsy (CP) and in para- or tetraplegic patients [3] [12] [14] [15] [16]. Contrary to the dorsal rhizotomy, the sensory fibers are spared with the MSN. MSN has to be performed before osteoarticular or osteomuscular anomalies occur. If these complications are already present, MSN should be complemented with an orthopedic correction [17] [18].

In cases of disabling spastic equinus foot, MSN is performed on the soleus and gastrocnemius nerves, as well as the posterior tibial nerve. All are nerves arising from the tibial nerve. If "claw" toes are present and disabling, MSN is performed on fascicles of the flexor digitorum, which are encountered within the tibial nerve, distally of the exit of the posterior tibial nerve. Concerning the superior limbs, MSN is performed on the median nerve for the spastic wrist and finger flexion; on the musculo-cutaneous nerve for the spastic elbow flexion; and on the ulnaris nerve for the spastic cubital deviation of the wrist. It has also been suggested that the MSN technique could offer advantages when treating the spastic shoulder [19] [20].

A notable improvement of the residual voluntary motility has been suggested (Marc Sindou, personal communication, 1997) following successful MSN procedure, due to a regained balance between agonist and antagonist muscles. Relapses are rare since nerve interruption in this technique is definitive. Good results have been shown to be obtained even in cases of spasticity lasting up to 15 years [5] [6] [21]. We initiated this experience in 1997 [9]. Methods and results exposed in this work are based on our experience during the last 10 years.

## 2. Method and Patients

We retrospectively analyzed the cases of 68 patients, operated on from 2005 to 2015 (**Table 1**). Thirty six (36) women and 32 men, ranging from 27 to 72 years old, were spastic due to such causes as: cerebral stroke (n = 40), trauma (n = 15), tumor (n = 4), cerebral aneurism and vascular malformation (n = 5), and multiple sclerosis (n = 4) (**Figure 1**). Surgeries were performed on the upper limb (87 nerves in 40 arms) or on the lower limb (211 nerves in 49 legs).

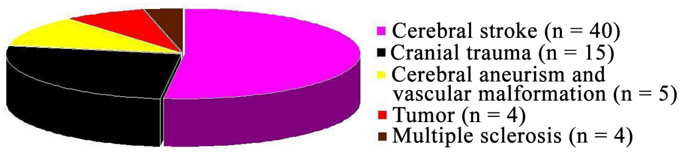



**Figure 1.** Distribution of causes of spasticity among operated patients from 2002-2012. Cerebral stroke and cranial trauma were the most frequent causes.

**Table 1.** Patient demographic data.

| **Patients** | ***n*** | | |
|---|---|---|---|
| Men | 32 | **Limbs operated on in the same patient** | |
| Women | 36 | Upper and lower limb | 21 |
| **Total** | **68** | One limb | 47 |
| **Patients/limbs** | | | **68** |
| Patients operated on 1 limb | 47 | | |
| Patients operated on 2 limbs | 21 | | |
| **Total** | **68** | | |
| **Causes** | | **Type of spastic paresia** | |
| Stroke | 40 | hemiparetic | |
| Trauma | 15 | hemiparetic | |
| Tumor | 4 | hemiparetic | |
| Aneurism, AVM | 5 | hemiparetic | |
| MS | 4 | paretic both sides | |
| **Total** | **68** | | |
| **Procedures** | | ***n*** | |
| Upper Limb | 31 arms | 67 nerves | |
| Lower Limb | 29 legs | 151 nerves | |
| **Total procedures** | 60 limbs | 218 nerves | |

**Patient selection**

Patients suffering mainly from focal spasticity were selected. Their spasticity was limited to either the superior or inferior limb, or the bilateral inferior limbs. The majority of patients were hemiplegic and conservative treatments such as physiotherapy and/or neuro-muscular blocks were no longer satisfactory in relieving spasticity. Patients were evaluated in order to predict long lasting consequences of spasticity: in hand or foot, pelvis statics, knee, elbow and wrist, and trophic deformities [22]. The muscles responsible for incapacitating spasticity were identified according to their peripheric and metameric innervation.

The inclusion criteria were: 1) a diagnostic of focal spasticity, in upper limb and/or lower limb due to a neurologic lesion; 2) age between 20 - 70 years old; 3) spasticity of grade 3 or more of the Ashworth modified scale; 4) absence of joint, ligamentous or joint irreversible limitations; 5) three or more years with neuromuscular blocks treatment and physiotherapy, now without good results; 6) consent and acceptance of the surgical treatment. The exclusion criteria comprised: 1) a diagnostic of focal spasticity, in upper limb and/or lower limb due to a neurologic lesion; 2) age between 20 - 70 years old; 3) spasticity of grade 3 or more of the Ashworth modified scale; 4) absence of joint, ligamentous or joint irreversible limitations; 5) three or more years with neuromuscular blocks treatment and physiotherapy, now without good results; 6) consent and acceptance of the surgical treatment.

If passive motility of limbs is not possible or is not conclusive, a nerve block test should be performed. The anesthetic block was prepared with marcaine, lidocaine, or bupivacaine and injected in the vicinity of the nerve to be treated.

Block test in the upper limb. In the sub-bicipital space, the brachial artery pulse is palpated. The injection should be done in the vicinity and 5 ml of the selected anesthetic is injected, after gentle aspiration. If arterial blood is obtained during aspiration, it is just necessary to move to a different location before injection. The anesthetic bathes the median and musculo-cutaneous nerves and after 1 hour the arm should be relaxed and easy to explore.

Block test in the lower limb. In the popliteal fossa, the femoral pulse should be encountered. Again, the injection should be done in the vicinity of the artery and care must be taken to avoid the artery, as described above. One hour after the injection of 5 ml of the anesthetic the foot and toes should be relaxed and can be examined.

This test abolishes spasticity for several minutes and thus tendinous and ligament retractions or capsuloarticular limitations become evident [23]. In addition, it permits the appreciation of what improvements may be possible after completion of the surgery. Altogether, both the physical examination and the nerve block test described here make it possible to establish the surgical strategy of the MSN, *i.e.*, which nerve is to be treated and the amount of nerve resection, expressed in percentage (50%, 60%, 75%, 80%) or in fraction (2/4, 3/4, 3/5, 4/5). For a long lasting test, it is preferable to perform the nerve block with botulinum toxin [2].

**Surgical technique**

In the upper limb, the musculo-cutaneus nerve is selected to treat the spastic flexion of the elbow; ulnaris nerve for the cubital deviation of the wrist; and the median nerve for the spastic flexion of the wrist and fingers. Spasticity and posture anomalies of the foot depend on muscles innervated by the tibial nerve, *i.e.*, soleus and gastrocnemius nerves for the spastic equinus foot and achillian clonus; posterior tibial nerve for the varus foot, and flexor digitorum for "claw" toes.

The operation is performed with general anesthesia devoid of neuromuscular blocking agents. Positioning of the patient should allow a physiotherapist to have access to the upper or lower limb in order to assess the motor responses triggered by intraoperative electric stimulation (Micromar Radiofrequency Generator MRFG-01B, Micromar®, Sao Paulo, Brasil). The musculo-cutaneous and median nerve are accessible behind the belly of the bicep muscle. The tibial nerve is approached through the popliteal fossa and its branches are encountered: lateral and medial gastrocnemius, soleus and posterior tibial nerves. The flexor digitorum fascicles are reached more inferiorly within the trunk of the tibial nerve (**Figure 2**).

Every nerve is identified and its perineurium opened with the aid of a peripheral nerve bipolar stimulation probe and surgical microscope. Fascicles within the endoneurium are separated and individually stimulated (0.5 - 2 volts) in order to perceive the amount of muscular contraction provocated (this also depends on the number of motor units of each one). Each selected fascicle is cut, removing a portion of it (3 to 5 mm) and thus leaving a gap between proximal

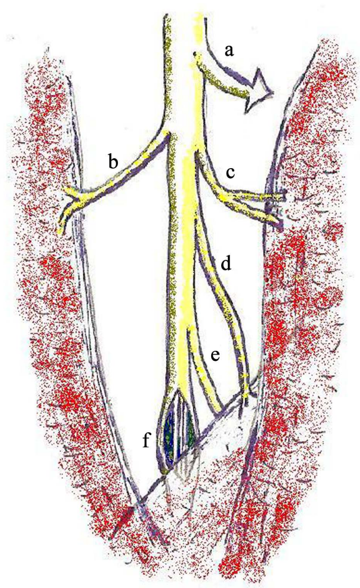



**Figure 2.** Branches of the tibial nerve in the popliteal fossa. (a) The common peroneal nerve has already exit; (b) Medial and (c) lateral gastrocnemius nerves; (d) Soleus nerve; (e) Posterior tibial nerve; (f) The flexor digitorum fascicles are reached within the trunk of the tibial nerve.

and distal end, and each end is coagulated, to prevent the least possibility of reconnection to occur (**Figure 3**). According to the preoperative program established with the physiatrist, a proportional number of fascicles are cut until proper reduction of the contraction is reached and it is assessed by tactil appreciation, based on the physiatrist experience. The preoperative program is based on the evaluation of each spastic muscle. For example if the bicipital muscle has a spasticity graded 3 in the Ashworth modified scale (MAS) [24] [25] the approximate percentage of bundles to be cut is 50% - 60%. For an MAS 4, 70% - 80%, and for an MAS 5, 80% - 90%.

**Postoperative follow-up**

The mean post-operative follow-up period was 26.4 months. Spasm and spasticity were objectively measured (**Table 2**). In order to quantify spasticity, we utilized a modified Ashworth scale (MAS). Residual voluntary movements after MSN surgery were assessed using the motor scale, which is used to measure muscular strength and motility (**Table 3**).

Spasticity is frequently accompanied by pain in the affected limbs. We used a visual analog scale (VAS) to assess the amount of pain that was ameliorated after MSN surgery. Follow-up was performed for up to 10 years, with a mean period of 29 months.

**Statistical analysis**

Data from upper and lower limb were analysed separately at the beginning and after 9-month follow up. A nonparametric test comparing the distributions of preoperative and postoperative MAS (Mann-Whitney two-tail test) was performed. GraphPad Prism software was used for all analysis (GraphPad Software, version 7.05 for Windows, La Jolla California USA, www.graphpad.com/).

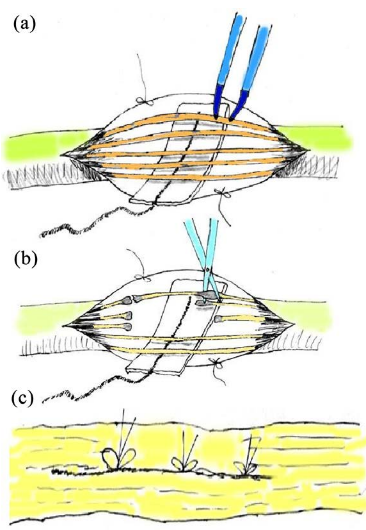


**Figure 3.** (a) Every nerve is identified and its perineurium opened. The bundes within the endoneurium are separated and individually stimulated (0.5 - 2 volts, Micromar Radiofrequency Generator MRFG-01B, Micromar®, Sao Paulo, Brasil) with the aid of a peripheral nerve stimulation probe; (b) Each selected fascicle is cut, removing a portion of it (3 to 5 mm) to prevent any reconnection to occur; (c) Then, the perineurium is closed anew.

**Table 2.** Spasticity and Spasms scales used in this work. Spasticity was measured using the modified Ashworth scale (MAS) [24] [25].

| Spasticity |
|---|
| *Absent*: 0 |
| *Light*: *1*; no functional disturbance is present, no vicious posture, easy passive movilization. |
| *Moderate*: 2; little functional disturbance, passive movilization restore vicious postures with some difficulty. |
| *Severe*: 3; severe functional disturbance, passive movilization hardly and uncompletely restore vicious postures. |
| *Major*: 4; great functional disturbance, passive movilization cannot restore vicious postures. |
| **Spasms** |
| *Ausente*: 0 |
| *Low*: 1; rare or weak, without any functional disturbance |
| *Moderate*: 2; frequent but low intensity, moderate functional disturbance |
| *Severe*: 3; very frequent and high intensity, severely functional disturbance |
| *Major*: 4; constant, intense, great functional disturbance |

**Table 3.** Motor scale used to measure muscular strength and motility.

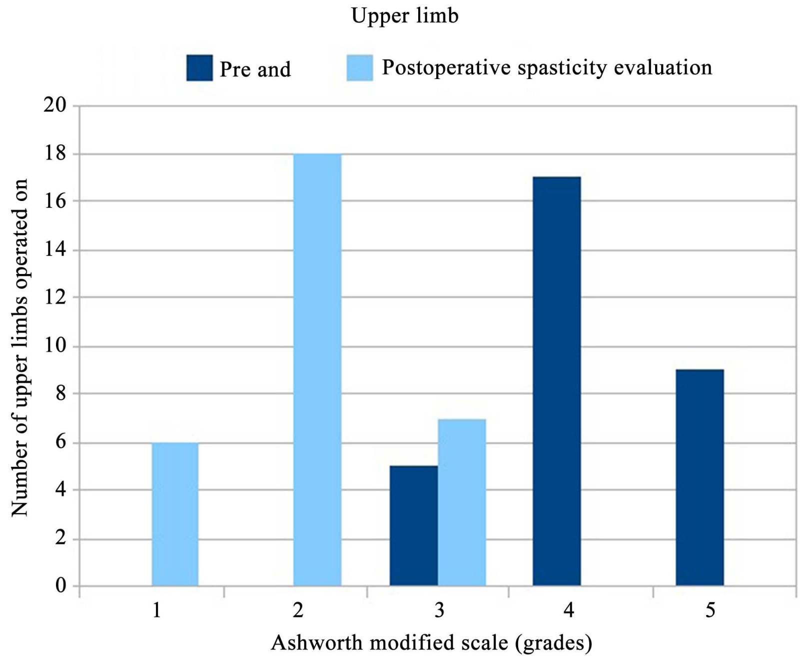
| Residual voluntary motility |
|---|
| 0: absence of movement |
| 1: movement over a surface, without elevation |
| 2: elevation, without standing any resistance |
| 3: elevation against resistance |
| 4: normal movement and normal muscular strength |

## 3. Results

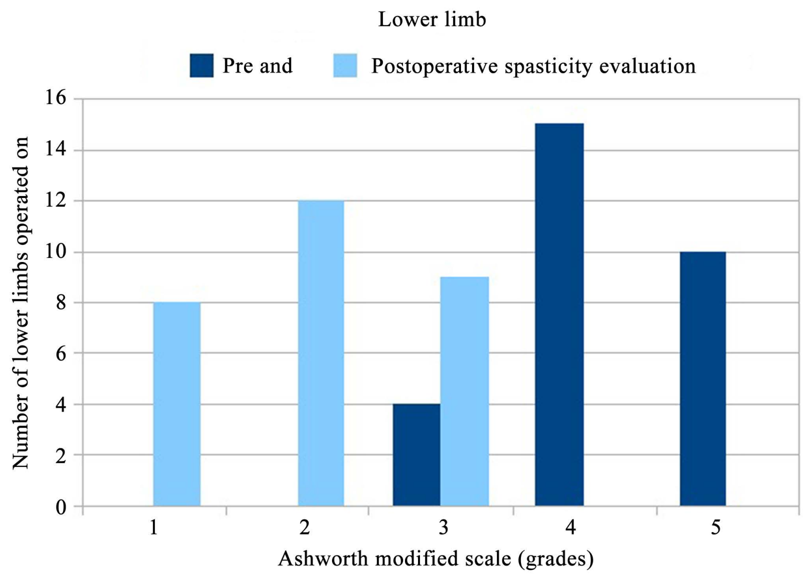
In all cases, MSN produced an immediate relaxation of the selected spastic muscles. We could observe good extension of elbow, wrist and fingers, as well as feet and toes, depending on whether MSN was performed in the superior or inferior limb(s). Afterward, during the postoperative period, we observed a tendency of regaining the previous vicious posture, which can be avoided by establishing a vigorous program of physiotherapy following surgery.

**Effects of MSN on spasticity and spasms**

Results can be observed in **Figure 4(a)** and **Figure 4(b)**, where it is illustrated the outcome of MSN in pre-and postoperative (average 29 months) spasticity per limb. On 68 patients, we operated on 40 arms and 49 legs, performing 298 MSN: 87 nerves in the upper limb (median nerve 40, musculo-cutaneous nerve 38, cubital nerve 9) and 211 nerves in the lower limb (lateral 49, and medial 49 gastrocnemius nerves, soleus nerve 49, tibial posterior nerve 45, digitorum flexor 19). Among those patients who had MSN surgery in the lower limb, 28 had achilian clonus. This clonus disappeared in 21 patients and in 7 patients was partially




(a)




(b)

**Figure 4.** (a) MAS of the upper limb before and after microselective neurotomy. Pre-operative MAS of 4.154 ± 0.1323, is significantly reduced to 2.038 ± 0.1299 at 9 month follow up. Mann-Whitney non-parametric two tail test was used ($p < 0.0001$). *Preoperative*: *dark columns*. *Postoperative*: *light columns*; (b) MAS of the lower limb before and after microselective neurotomy. Pre-operative MAS 4.095 ± 0.1528 is significative reduced to 2.095 ± 0.1677 at 9-month follow up. Mann-Whitney non-parametric two-tail test was used ($p < 0.0001$). *Preoperative*: *dark columns*. *Postoperative*: *light columns*.

reduced. Spasms occurred predominantly in the lower limb, with a score of 3 before surgery, and 1 postoperatively.

**Effects of MSN on pain**

Fourteen (14) out of 68 patients who underwent MSN surgery complained of pain, which was totally relieved postoperatively in 12 patients, according to their Visual Analog Scale (VAS) ratings. In 2, pain was alleviated in 40%.

**Effects of MSN on residual voluntary movements**

Residual voluntary movements after MSN surgery were only evident and functional in the upper limb, especially in the hand. In 40 patients who underwent MSN of the median nerve for wrist and finger spasticity, a voluntary flexion of wrist and fingers (hand apprehension) re-emerged and could be observed in 16 patients. This motility was functional since the hand could be used as a clamp to hold tools (pen, fork) for a purposed action.

**Complication of surgery**

In 2 patients operated on in the upper limb a transient neuropathic pain appeared after the surgery in the same arm. We concluded that it may be caused by lesion of some sensory branches within the median nerve. These 2 patients were treated with gabapentin, and after 4 and 5 months the pain disappeared.

## 4. Discussion

MSN is the surgical technique introduced by Sindou and Mertens [21]. This procedure is commonly used in neurosurgical centers in the east world, but few experiences have been published from the American continent, and yet, MSN is the best alternative to neuro-muscular blocks, when they are no longer fruitful. MSN partially eliminates motor innervation of spastic muscles, sparing some motor fibers in order to leave certain amount of muscular tonus. Contrary to posterior radicellotomy [26], sensation is preserved in MSN since only motor nerves are sectioned. With a better balance between agonists and antagonists muscles, achieved with the MSN, residual voluntary movements become evident. MSN is normally indicated when other more conservative procedures are fruitless. However, due to its relatively innocuous nature, it can be discussed whether MSN could be indicated as a first approach in certain and selected cases. In this regard, a clinical protocol to address this issue can be proposed. Nonetheless, MSN is the procedure of choice as an alternative of neuro-muscular blocks.

While short term positive effects on spasticity have been observed with MSN, it has been debated whether MSN will remain beneficial in the long term. Although some are not convinced of long term results [27], there is strong evidence that MSN can offer long lasting effects from 2 to 15 years after the procedure is completed [28] [29] [30]. Moreover, this can be a great advantage on neuromuscular blocks with botulinum toxin [31]. Relapse of spasticity can be explained by the sprouting of synaptic terminals of the neuromuscular junction which results in an enlarged motor unit [32] or reconnection of the sectioned nerve. To prevent any possibility of reconnection to occur in the sectioned nerve, a portion of each bundle is removed, leaving a gap between proximal and distal end, and in addition, each end is coagulated. However, in our opinion, regaining the previous spastic posture is explained by both the persistence of a vicious position because of a cerebral motor engram and by a ligamentous-articular deformity installed long before the surgery. For this reason, we strongly advocate for an immediate postoperative program of physiotherapy and reeducation in order to take advantage of the new (relaxed) neuro-motor situation resulting from surgery and to avoiding osteo-ligamentous-articular deformities from forming later. In addition, with an early and immediate physiotherapy regimen, it is more likely for residual voluntary movements to reappear post-surgery.

It has been suggested that a percutaneous neurotomy with the use of radio-frequency [33] [34] could have the same effect on spasticity. This modality is attractive for its simplicity and the lack of necessity of open surgery. We have had a modest experience in 2 cases; however, we did not notice a significant post-operative benefit in these patients. Nonetheless, we will have this alternative procedure available in situations where open surgery cannot be performed.

Other peripheral nerves were described for selective neurotomy that were not considered in this paper as, sciatic, obturator, pectoral major nerve and spinal nerves [16] [35] [36]. These options are very suitable for spastic shoulder, lateral wist, flexed knees or crossed legs spastic deformities.

This work does not pretend to be a conclusive study. Therefore, more extensive research in the application of MSN to resolve focal spasticity is currently being prepared. It includes recent and prospective cases in which we are using additional measurements of postoperative progress, such as articular amplitude, Hoffmann reflex, postoperative EMG, and gait analysis [30] [37] [38] [39].

## 5. Conclusion

In conclusion, MSN can offer an efficient and effective alternative to treat focal spasticity of limbs in cases where conservative measures such as physiotherapy and neuromuscular blocks are unsatisfactory in relieving spasticity.

## Dedication

This article is specially dedicated to Professor Marc Sindou from which the principal author has learned the indications and surgical techniques and, in turn, has taught the other co-authors.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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