Dystonia and Peripheral Nerve Surgery in the Cervical Area

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1. Introduction

Cervical dystonia is the most common form of focal dystonia (Dashtipour et al., 2007). It is characterized by involuntary movement of the neck resulting in abnormal neck posture (Brin & Benabou, 1999; Dent, 2002). Cervicalgia and headache sometimes occur in patients suffering from the disease (Albanese, 2005; Brashear, 2004, Schim, 2006). A critical long-term sequelae of this kind of movement disorder is premature cervical spinal degenerative disease (Chawda et al., 2000) which possibly progresses to cervical spondylotic myelopathy (Hagenah et al., 2001; Jameson et al., 2010; Konrad et al., 2004; Krauss et al., 2002; Spitz et al., 2006; Tonomura et al., 2007; Waterston et al., 1989).

Fundamentally, cervical dystonia is categorized into several patterns, including torticollis (head rotation), anterocollis (head forward flexion), retrocollis (head backward extension), laterocollis (lateral head bending), and combined pattern (Brin & Benabou, 1999; Feely, 2003; Sitthinamsuwan & Nunta-aree, 2010; Sitthinamsuwan et al., 2010a). The last mentioned pattern is comprised of two or more dystonic patterns. Dystonic muscles in each pattern are quite unique. For instance, involved muscles in torticollis include the posterior cervical muscles (mainly splenius capitis, semispinalis capitis and semispinalis cervicis) on the same side of turning head and the contralateral sternocleidomastoid. The various dystonic patterns and corresponding neck muscles are summarized in Fig.1 (Brashear, 2004; Brin & Benabou, 1999; Dashtipour et al., 2007; Dent, 2002; Feely, 2003; Huh et al., 2005; Sitthinamsuwan & Nunta-aree, 2010; Sitthinamsuwan et al., 2010a). An example of the combined pattern is presented in Fig.2.

Conventional treatment of cervical dystonia consists of oral medication, botulinum toxin injection, and physical therapy. For patients who do not respond to such therapies or are refractory cases, surgical treatment is an appropriate option (Nunta-aree & Sitthinamsuwan, 2009; Nunta-aree et al. 2010a, 2010b). Surgical therapy for cervical dystonia has been continuously developed for a significant period to improve outcome and diminish complication. Some operations have been abandoned because of their potential complications while some of them have been used increasingly and are currently popular on account of their effectiveness and safe (Albanese, 2005; Albanese et al., 2006; Brin & Benabou, 1999; Feely, 2003). Overview of surgical treatment for cervical dystonia is described in the following.

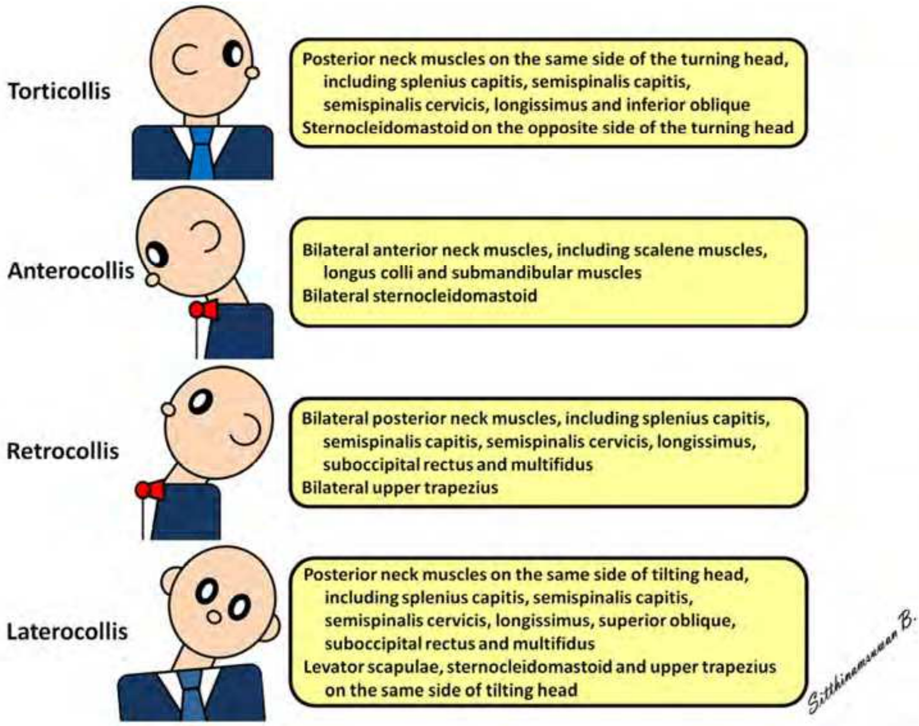

Fig. 1. Various patterns of cervical dystonia. The involved cervical muscles are shown in the yellow boxes.

Fig. 2. A combined pattern of cervical dystonia in the same patient. A, The anterior view shows right torticollis with left laterocollis. B, Left laterocollis can be clearly seen in the posterior view.

a) Intradural anterior cervical rhizotomy

Originally, bilateral C1-C3 anterior spinal nerve roots were resected intradurally in this operation (Münchau et al., 2001a; Taira, 2009). A significant numbers of patient developed swallowing dysfunction following the surgery while improvement of cervical dystonia was not appreciable. Consequently, there is no use of bilateral C1-C3 anterior rhizotomy in the present (Brin & Benabou, 1999; Bronte-Stewart, 2003; Taira, 2009). However, recently, intradural C1-C2 anterior rhizotomy has been successfully combined with selective denervation of C3-C6 posterior rami successfully without serious adverse effect (Taira et al.; 2002; Taira & Hori, 2003; Taira, 2009).

b) Intradural posterior cervical rhizotomy

The formerly common procedure was bilateral C1-C4 posterior rhizotomy (Vogel et al., 2010) which was ultimately proved ineffective in the treatment of cervical dystonia. It sometimes caused respiratory insufficiency as a result of diaphragmatic dysfunction (Fraioli et al., 1977). Nowadays, posterior rhizotomy in the cervical level are performed only on C5 to T1 posterior nerve spinal roots and it aims to treat bilateral upper limb spasticity (Benedetti et al, 1977; Bertelli et al., 2000, 2003; Heimburger 1973; Hsin et al., 2004, Laitinen et al., 1983).

c) Intradural accessory nerve denervation

This abandoned method was resection of the accessory nerve situated in the posterior cranial fossa (Adams, 1984; Hernesniemi & Keränen, 1990). It affected not only motor fibers to the sternocleidomastoid but also those to the trapezius. Postoperative trapezius atrophy and shoulder instability inevitably occurred (Bronte-Stewart, 2003; Sorensen & Hamby 1965).

d) Stereotactic brain lesioning

Bilateral thalamotomy used to be an effective stereotactic ablative surgery for cervical dystonia (Bronte-Stewart, 2003; Dashtipour et al., 2007). Bilateral procedures, however, commonly resulted in speech disturbance (Bronte-Stewart, 2003; Imer et al., 2005; Krauss, 2010). Presently, it is completely replaced by pallidal deep brain stimulation.

e) Microvascular decompression of the accessory nerve

This rarely used operation primarily aims to rectify dystonia of the sternocleidomastoid and trapezius in patients with torticollis (Sun et al, 2009). Nevertheless, the hypothesis of accessory nerve decompression cannot explain improvement of cervical dystonia in the individuals who have no dystonia of both the muscles (Albanese et al., 2006; Brin & Benabou, 1999; Bronte-Stewart, 2003; Taira, 2009).

f) Selective peripheral denervation

This relatively safe and popularly used procedure is an ablative surgery specific on peripheral motor nerves innervating dystonic neck muscles whereas motor branches supplying normal muscles and sensory nerves will be entirely preserved (Bertrand, 1987, 1993; Braun & Richter, 1994). Good to excellent outcome is often achieved by the operation, so it has become a common surgical treatment for cervical dystonia (Albanese, 2005; Albanese et al., 2006; Krauss, 2010). This type of surgery is the central idea of the present chapter and its content will be stated in detail.

g) Myotomy or myectomy

Resection of dystonic muscles is occasionally combined with selective peripheral denervation (Albanese et al., 2006; Bronte-Stewart, 2003; Chen et al., 2000; Huh et al., 2005; Krauss, 2010; Münchau et al., 2001a; Xingkang, 1981). In the authors view, muscle section is an adjunctive procedure for cervical dystonia and should be considered in cases with long-standing dystonia which exhibit evidence of soft tissue stiffness or muscle shortening. Furthermore, it may be performed on muscles which are difficult to denervate (Ondo & Krauss, 2004), such as the scalene muscles.

h) Pallidal deep brain stimulation

High-frequency stimulation of the globus pallidus internus often yields outstanding result in dystonic individuals, including patients with cervical dystonia (Albanese et al., 2006; Bittar et al., 2005; Cacciola et al., 2010; Hung et al., 2007; Krauss et al., 1999, 2004; Krauss, 2007; Parkins et al., 2001; Vercueil, 2003; Volkmann & Benecke, 2002; Yianni et al., 2003). However, among our patients with uncomplicated or simple cervical dystonia, we did not encounter substantial difference of outcome between the patients who underwent pallidal deep brain stimulation and those who underwent peripheral denervation. Therefore, we always chose peripheral nerve resection as the primary surgical therapy in the uncomplicated cases. On the other hand, we consider the deep brain stimulation as the prerequisite treatment of complex cervical dystonia, such as mobile cervical dystonia, segmental dystonia, head tremor, anterocollis, severe retrocollis, in the patients who have significant extracervical symptoms, or who have never been improved by botulinum toxin injection (primary botulinum toxin non-responder). Such complicated cases are always difficult to deal with through selective peripheral denervation (Albanese et al., 2006; Krauss, 2010; Nunta-aree & Sitthinamsuwan, 2009; Nunta-aree et al., 2010a, 2010b).

i) Intrathecal baclofen therapy

Implantation of this kind of intraspinal drug delivery system is more suitable for generalized dystonia or multifocal dystonia than focal dystonia at the neck (Albright et al., 2001; Dykstra et al., 2005).

j) Spinal cord stimulation

Dorsal column stimulation of the spinal cord gave inconstant outcome and there was no continuous study in dystonic patients since 1990s (Fahn, 1985; Taira & Hori, 2007; Taira, 2009). However, currently, it appears to be a good surgical option in various pain disorders, particularly in neuropathic pain and pain of ischemic origin (Forouzanfar et al., 2004; Kunnumpurath et al., 2009).

This chapter focuses on peripheral nerve surgery in the cervical region for cervical dystonia which refers to selective peripheral denervation in terms of patient selection, preoperative evaluation, operative procedures with relevant surgical anatomy, and surgical outcome.

2. Patient selection

Selective peripheral denervation is chiefly indicated in patients with failed botulinum toxin injection, including those who have never responded to the injection (primary botulinum toxin non-responder) or who have a change from significant previous response to poor recent response (secondary botulinum toxin non-responder) (Albanese et al., 2006; Brin & Benabou, 1999; Bronte-Stewart, 2003; Feely, 2003; Taira, 2009;). Good surgical candidates for the operation include those who meet the following parameters (Braun et al., 1995; Brin & Benabou, 1999; Chen et al., 2000; Dashtipour et al., 2007; Feely, 2003, Nunta-aree et al., 2010b).

a. Patients who are botulinum toxin responder or even secondary non-responder
b. Dystonic symptoms have been stable or not progressed at least 1 year
c. Dystonic disorder mainly confines in the neck region
d. Pure torticollis with slight laterocollis or retrocollis
e. Preoperative electromyography and imaging of the cervical muscles are concordant with clinical manifestation

Furthermore, selective peripheral denervation is sometimes considered as a major alternative to botulinum toxin injection in the treatment of cervical dystonia. For example, for patients who do not require multiple repeated injections or who cannot afford the cost of the toxin, the operation is meaningful for them (Taira, 2009). Nevertheless, some kinds of cervical dystonia are not suitable for the procedure, including head tremors, anterocollis, complex cervical dystonia or cervical dystonia with marked phasic movement. In such kinds of dystonia, pallidal deep brain stimulation should be considered first (Albanese et al, 2006; Nunta-aree et al., 2010b).

3. Preoperative evaluation

In the surgical point of view, consideration before decision of the denervating procedure should cover the following.

3.1 Identification of dystonic muscles

Basically, dystonic muscles must be always defined by using clinical observation and physical examination. Visualization of abnormal posture of the neck, palpable deviant muscle tone and tension usually give valuable preliminary information about the group of involved muscles. Electromyography or video-electromyography is an important tool to define the specific group of dystonic muscles (Brin & Benabou, 1999; Dressler, 2000; Feely, 2003; Krauss et al., 1997; Münchau et al., 2001a; Ostergaard et al., 1996), for which it is very helpful in operative planning. Recently, FDG PET-CT was introduced in localization of dystonic muscles in the neck region (Sung et al., 2007).

3.2 Prior response to botulinum toxin injection

As mentioned above, patients with good prior response to the toxin have tendency to achieve good outcome following the operation, whereas the primary non-responders may not (Braun et al., 1995). The information about injected muscles which accomplish good outcomes is very critical for operative planning.

3.3 Fixed bony deformity

This secondary change should be investigated, especially in patients who have long-lasting cervical dystonia. It can be simply revealed by noting passive range of motion of the neck and plain radiographic studies of the cervical spine. Limitation of passive neck motion implies probable fixed deformity which often impairs surgical outcome, particularly in terms of postoperative neck posture.

3.4 Measure of cervical dystonia

The commonly used measures of cervical dystonia severity and its impacts are The Toronto Western Spasmodic Torticollis Rating Scale (TWSTRS) and Tsui score (Cano et al., 2004; Ceballos-Baumann, 2001; Comella et al., 2003; Taira, 2009; Tsui et al., 1986). The TWSTRS (Comella et al., 1997) (Table 1) is comprised of three main sections, including torticollis severity scale, disability scale, and pain scale. The Tsui score (Moore & Blumhardt, 1991; Tsui et al., 1986) (Table 2) is a composite score calculated by a formula. By both the methods, a higher level of score indicates increased severity of cervical dystonia (Comella et al., 1997; Moore & Blumhardt, 1991). The score can be used for comparison between before and after a treatment or between among various alternatives of treatment.

1. Torticollis severity scale (maximum = 35)			
A. Maximal excursion			
Rotation *(turn: right or left)*		0	None (0°)
		1	Slight (< 1/4 range, 1° - 22°)
		2	Mild (1/4 - 1/2 range, 23° - 45°)
		3	Moderate [1/2 - 3/4 range, 46° - 67°)
		4	Severe (>3/4 range, 68° - 90°)
Laterocollis *(tilt: right or left, exclude shoulder elevation)*		0	None (0°)
		1	Mild (1° - 15°)
		2	Moderate (16° - 35°)
		3	Severe (> 35°)
Anterocollis or retrocollis (a or b)	a. Anterocollis	0	None
		1	Mild downward deviation of chin
		2	Moderate downward deviation (approximates 1/2 possible range)
		3	Severe (chin approximates chest)
	b. Retrocollis	0	None
		1	Mild backward deviation of vertex with upward deviation of chin
		2	Moderate backward deviation (approximates 1/2 possible range)
		3	Severe (approximates full range)
Lateral shift *(right or left)*		0	Absent
		1	Present
Sagittal shift *(forward or backward)*		0	Absent
		1	Present
B. Duration factor *(weighted x 2)*			
Duration factor *(weighted x 2)*		0	None
		1	Occasional deviation (< 25% of the time, most often submaximal)
		2	Occasional deviation (< 25% of the time, often maximal) or Intermittent deviation (25 - 50% of the time, most often submaximal)
		3	Intermittent deviation (25 - 50% of the time, often maximal) or Frequent deviation (50 - 75% of the time, most often submaximal)
		4	Frequent deviation (50 - 75% of the time, often maximal) or Constant deviation (>75% of the time, most often submaximal)
		5	Constant deviation (>75% of the time, often maximal)

C. Effect of sensory tricks		
Effect of sensory tricks	0	Complete relief by one or more tricks
	1	Partial or only limited relief by tricks
	2	Little or no benefit from tricks
D. Shoulder elevation/Anterior displacement		
Shoulder elevation/Anterior displacement	0	Absent
	1	Mild (< 1/3 possible range, intermittent or constant)
	2	Moderate (1/3 - 2/3 possible range and constant, > 75% of the time) or Severe (> 2/3 possible range and intermittent)
	3	Severe and constant
E. Range of motion *(without aid of sensory tricks)*		
Range of motion *(without aid of sensory tricks)*	0	Able to move to extreme opposite position
	1	Able to move head well past midline but not to extreme opposite position
	2	Able to move head barely past midline
	3	Able to move head toward but not past midline
	4	Barely able to move head beyond abnormal posture
F. Time *(up to 60 seconds) for which patient is able to maintain head within 10º of neutral position without using sensory tricks (mean of two attempts)*		
Time	0	> 60 seconds
	1	46 - 60 seconds
	2	31 - 45 seconds
	3	16 - 30 seconds
	4	< 15 seconds
2. Disability scale (maximum = 20)		
A. Work *(occupation or housework/home management)*	0	No difficulty
	1	Normal work expectations with satisfactory performance at usual level of occupation but some interference by torticollis
	2	Most activities unlimited, selected activities very difficult and hampered but still possible with satisfactory performance
	3	Working at lower than usual occupation level; most activities hampered, but all possible with less than satisfactory performance in some activities
	4	Unable to engage in voluntary or gainful employment; still able to perform some domestic responsibilities satisfactorily
	5	Marginal or no ability to perform domestic responsibilities
B. Activities of daily living *(e.g., feeding, dressing, or hygiene, including washing, shaving, makeup, etc.)*	0	No difficulty with any activity
	1	Activities unlimited but some interference by torticollis
	2	Most activities unlimited, selected activities very difficult and hampered but still possible using simple tricks
	3	Most activities hampered or laborious but still possible; may use extreme tricks
	4	All activities impaired; some impossible or require assistance
	5	Dependent on others in most self-care tasks

C. Driving	0	No difficulty (or has never driven a car)
	1	Unlimited ability to drive but bothered by torticollis
	2	Unlimited ability to drive but requires tricks (including touching or holding face, holding head against head rest) to control torticollis
	3 4 5	Can drive only short distances Usually cannot drive because of torticollis Unable to drive and cannot ride in a car for long stretches as a passenger because of torticollis
D. Reading	1	Unlimited ability to read in normal seated position but bothered by torticollis
	2	Unlimited ability to read in normal seated position but requires use of tricks to control torticollis
	3	Unlimited ability to read but requires extensive measures to control torticollis or is able to read only in nonseated position (e.g., lying down)
	4	Limited ability to read because of torticollis despite tricks
	5	Unable to read more than a few sentences because of torticollis
E. Television	0	No difficulty
	1	Unlimited ability to watch television in normal seated position but bothered by torticollis
	2	Unlimited ability to watch television in normal seated position but requires use of tricks to control torticollis
	3	Unlimited ability to watch television but requires extensive measures to control torticollis or is able to view only in nonseated position (e.g., lying down)
	4 5	Limited ability to watch television because of torticollis Unable to watch television more than a few minutes because of torticollis
F. Activities outside the home *(e.g., shopping, walking about, movies, dining, and other recreational activities)*	0	No difficulty
	1	Unlimited activities but bothered by torticollis
	2	Unlimited activities but requires simple tricks to accomplish
	3	Accomplishes activities only when accompanied by others because of torticollis
	4	Limited activities outside the home; certain activities impossible or given up because of torticollis
	5	Rarely if ever engages in activities outside the home
3. Pain scale (maximum = 20)		
A. Severity of pain	Rate the severity of neck pain due to spasmodic torticollis during the last week on a scale of 0 - 10 where a score of 0 represents no pain and 10 represents the most excruciating pain imaginable. Score calculated as: [worst + best + (2 x usual)]/4 Best ____ Worst ____ Usual ____ Score____	
B. Duration of Pain	0	None
	1	Present < 10% of the time
	2	Present 10 - 25% of the time
	3	Present 26 - 50% of the time
	4	Present 51 - 75% of the time
	5	Present > 75% of the time

C. Disability due to pain	0	No limitation or interference from pain
	1	Pain is quite bothersome but not a source of disability
	2	Pain definitely interferes with some tasks but is not a major contributor to disability
	3	Pain accounts for some (less than half) but not all of disability
	4	Pain is a major source of difficulty with activities; separate from this, head pulling is also a source of some (less than half) disability
	5	Pain is the major source of disability; without it most impaired activities could be performed quite satisfactorily despite the head pulling

Table 1. The Toronto Western Spasmodic Torticollis Rating Scale (TWSTRS) (Comella et al., 1997)

A. Amplitude of head deviation A = A1 + A2 +A3	A1. Rotation	0	Absent
		1	< 15°
		2	15 - 30°
		3	> 30°
	A2. Lateral head tilt	0	Absent
		1	< 15°
		2	15 - 30°
		3	> 30°
	A3. Antero/retrocollis	0	Absent
		1	< 15°
		2	15 - 30°
		3	> 30°
B. Duration of sustained movements		1	Intermittent
		2	Constant
C. Shoulder elevation		0	Absent
		1	Mild, intermittent
		2	Mild constant or severe intermittent
		3	Severe constant
D. Unsustained head movements *(head tremor/jerk)* D = D1 x D2	D1. Severity	1	Mild
		2	Severe
	D2. Duration	1	Occasional
		2	Continuous
Total score = (A x B) + C + D			

Table 2. The Tsui score (Tsui et al., 1986)

4. Operative procedures and relevant surgical anatomy

Selective peripheral denervation consists of several surgical procedures. One well-known operation is the Bertrand procedure which originally included section of peripheral branches of the cervical spinal nerve and selective denervation of the sternocleidomastoid nerve. Taira's method is a modification of the classic procedure of Bertrand aiming to overcome some drawbacks of the original method. Cutting of peripheral branches supplying the sternocleidomastoid or levator scapulae endeavors to reduce their dystonia resulting in improved neck posture and function. The authors simply divide the denervating procedures into three main themes, including denervation of the posterior cervical paraspinal, sternocleidomastoid, and levator scapulae muscles. In order to understand these operations, each of them will be preceded by exposition of its relevant surgical anatomy. In addition, identification of nerves by using intraoperative electrical nerve stimulator, conclusion of nerve supply to the neck muscles, options in selective denervation, and combined operations will be discussed consecutively.

4.1 Surgical anatomy of the posterior cervical paraspinal muscles and related nerve supply

In all patterns of cervical dystonia except for anterocollis, the posterior cervical paraspinal muscles have the key role in occurrence of dystonic postures. They are abnormal on the same side of rotating or tilting head in torticollis or laterocollis, respectively (Anderson et al., 2008; Krauss et al., 1997). This group of muscles are found to be dystonic bilaterally in retrocollis (Taira, 2009). The commonly involved muscles include the splenius capitis, semispinalis capitis, semispinalis cervicis, multifidus, suboccipital muscles (rectus capitis posterior major and minor, obliquus capitis superior and inferior), and upper trapezius (Taira, 2009) (Fig.3).

Aside from the trapezius, all of them are innervated by the posterior rami of the C1 to C8 spinal nerves while the upper twig of the accessory nerve directly supplies the trapezius. The most influent muscles are controlled by the C1 to C6 posterior rami. Consequently, a common procedure of posterior neck muscle denervation is C1-C6 posterior ramisectomy (Krauss et al., 1997).

The C1 dorsal root and its ganglion are usually absent (Tubbs et al., 2007), so the C1 spinal nerve mostly originates from the C1 ventral nerve root which contains pure motor fibers. The C1 segmental nerve emerges from the atlanto-occipital space located superior to the atlas, then it abruptly branches into the anterior and posterior rami. Unlike the C2 to C6 posterior rami, the C1 posterior ramus does not ramify into medial and lateral branches (Fig.4A) while those of the C2-C6 spinal nerves do (Clemente, 1985; Kahle & Frotscher, 2003; Kayalioglu, 2009; Roman, 1981). The posterior ramus of the C2 spinal nerve always bifurcates into medial and lateral branches. The medial branch mainly contains sensory fibers which it terminates as the greater occipital nerve supplying the posterior scalp up to the vertex (the C2 dermatome). The lateral branch is composed of motor fibers supplying the upper portion of the posterior cervical group (Fig.4B). The C3-C6 posterior rami often divide into medial and lateral branches innervating the corresponding skin as well as paraspinal muscles of the neck (Clemente, 1985; Kayalioglu, 2009; Roman, 1981) (Fig.4C).

4.2 Denervation of the posterior cervical paraspinal muscles

The two main strategic options in selective denervation of the posterior neck muscles are posterior cervical ramisectomy in the Bertrand procedure and Taira's modified method. The details of both alternatives are described as the follows.

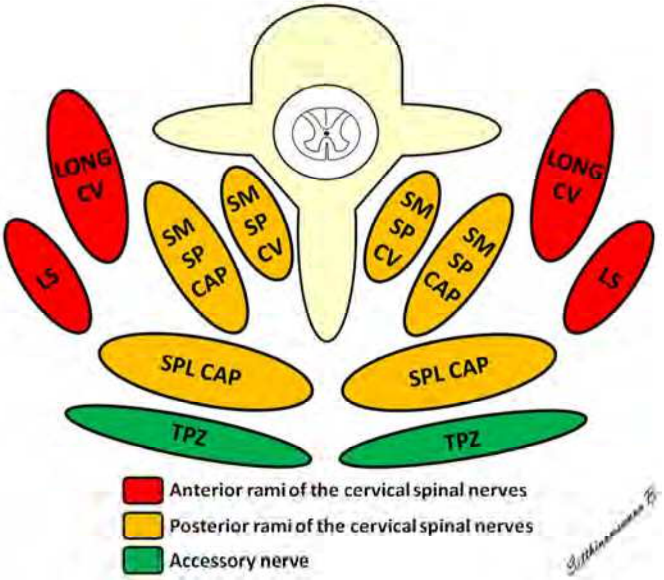

Fig. 3. Major cervical paraspinal muscles involved in cervical dystonia and their nerve supply. LONG CV, longissimus cervicis; LS, levator scapulae; SM SP CAP, semispinalis capitis; SM SP CV, semispinalis cervicis; SPL CAP, splenius capitis; TPZ, trapezius.

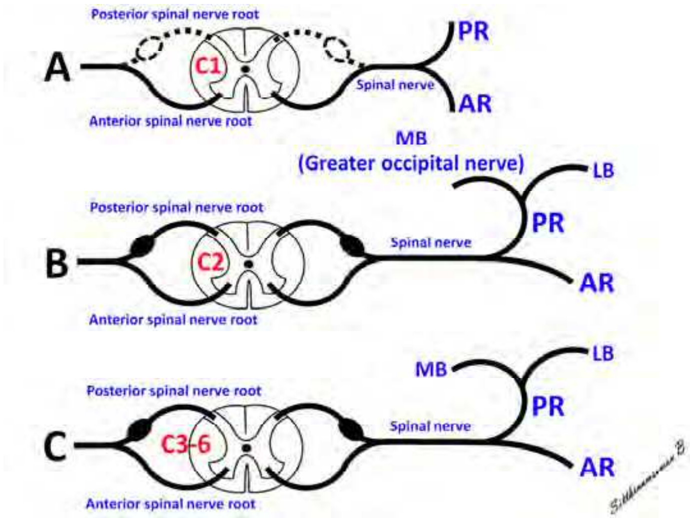

Fig. 4. The C1 - C6 spinal nerves and their branches. A, The C1 posterior root and ganglion are usually absent (dashed lines). The C1 spinal nerve directly arises from the C1 anterior spinal nerve root. The C1 spinal nerve branches into anterior ramus (AR) and posterior ramus (PR). The latter has no further ramification. For B and C, The posterior rami of C2 - C6 spinal nerves branch into medial branch (MB) and lateral branch (LB). The former, originating from the C2 level, terminates as the greater occipital nerve.

4.2.1 Posterior cervical ramisectomy in Bertrand procedure

Classically, peripheral denervation for torticollis in the Bertrand procedure is comprised of selective peripheral denervation of the posterior cervical muscles ipsilateral to the rotating head and selective denervation of the contralateral sternocleidomastoid muscle (Anderson et al., 2008; Bertrand, 1993; Braun & Richter, 1994; Feely, 2003; Krauss, 2010; Sitthinamsuwan et al., 2010b; Taira, 2009). This genuine extraspinal procedure provides good surgical outcome and is currently a widely used operation for cervical dystonia (Bronte-Stewart, 2003; Krauss, 2010; Sitthinamsuwan & Nunta-aree, 2010; Taira, 2009). Denervating procedure on peripheral nerves supplying the posterior cervical group is typically performed on those arising from the C1 to C6 spinal cord segment (Brin & Benabou, 1999; Dashtipour et al., 2007; Krauss, 2010; Sitthinamsuwan & Nunta-aree, 2010) through a midline posterior cervical incision (Fig.5). Original Bertrand's denervation of the posterior cervical muscles is comprised of extraspinal resection of C1-C2 spinal nerve roots (extraspinal C1-C2 rhizotomy) with section of C3-C6 posterior rami (C3-C6 posterior ramisectomy) (Bertrand, 1993; Huh et al., 2005, 2010). Alternatively, C1-C2 posterior ramisectomy can be used instead of C1-C2 extradural rhizotomy (Brin & Benabou, 1999; Münchau et al., 2001a; Ondo & Krauss, 2004). In the authors' practice deriving from C1-C2 operation, we preferred posterior ramisectomy rather than extraspinal rhizotomy. Therefore, C1-C6 posterior ramisectomy was always performed in our denervation. During dissection, muscular branches emerging from the C1-C6 posterior rami are identified by using an electrical stimulator and prepared for ramisectomy. The ablation is done just before the peripheral nerves penetrating the targeted muscles (Fig.6).

Fig. 5. A midline surgical incision on the back of the neck in posterior cervical ramisectomy

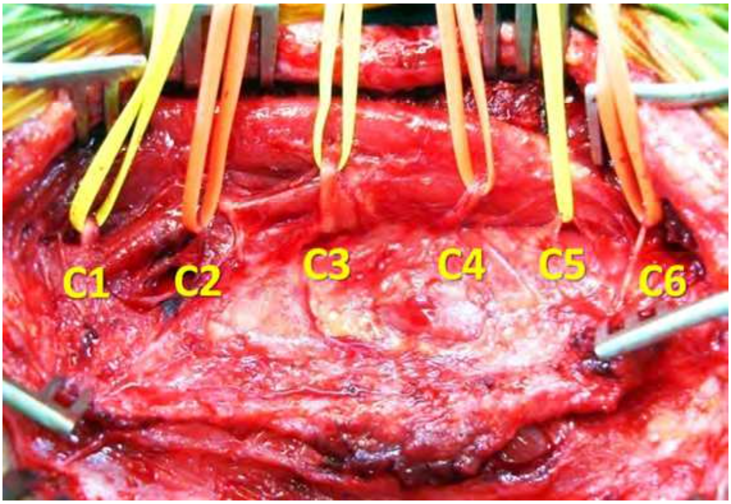

Fig. 6. Operative exposure of selective denervation in the posterior neck region. The muscular branches of the C1-C6 nerves supplying dystonic muscles on the affected side are identified and subsequently sectioned.

A common pitfall of posterior cervical ramisectomy is inadequate denervation of the semispinalis capitis resulting in residual or recurrent cervical dystonia. The pitfall may occur as a result of complex innervation of this muscle comprised of two entities. The first one is motor branches originating from the medial branches of the posterior cervical rami. They intervene in the plain between the semispinalis capitis and semispinalis cervicis and then enter into the deep surface of the semispinalis capitis (Fig.7A). In the same manner, the other entity is muscular branches coming from the lateral branches of the posterior cervical rami which they are situated in the plain between the semispinalis capitis and splenius capitis, then supply the semispinalis capitis through its superficial aspect (Taira, 2009) (Fig.7B). Hence, to accomplish complete denervation of the semispinalis capitis, exploration and resection of the motor nerves in both the plains are mandatory.

In patients suffering from retrocollis, bilateral posterior cervical muscle denervation is required. With caution, bilateral section of the C6 posterior rami should be avoided, particularly in elderly females who have thin neck muscles. Following bilateral C6 posterior ramisectomy, such patients probably develop difficulty in their neck extension and swallowing (Bertrand, 1988; Taira 2009). In our experience of bilateral posterior cervical denervation for intractable retrocollis, we always performed C1-C6 posterior cervical ramisectomy on a more severe side and cut from the C1 posterior ramus caudally to the C4 or C5 posterior ramus with total preservation of the C6 one on the contralateral side.

A major sequelae of Bertrand procedure is dysesthesia over the skin innervated by the C2 spinal nerve. The sensory disturbance of the C2 dermatome is inevitable in almost all cases who undergo this procedure. It always occurs in the early postoperative period as a result of resection of the proximal C2 dorsal ramus containing both motor and sensory nerve fibers (Albanese et al., 2006; Braun & Richter, 1994; Feely, 2003; Münchau et al., 2001a;

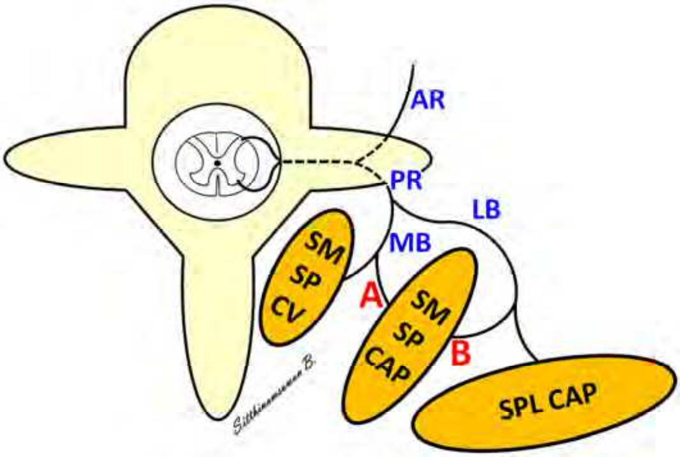

Fig. 7. Innervation of the semispinalis capitis muscle (SM SP CAP). A and B are the muscular branches arising from the medial branch (MB) and lateral branch (LB) of the posterior cervical rami (PR), respectively. They supply the semispinalis capitis through its opposite surfaces. AR, anterior cervical rami; SM SP CV, semispinalis cervicis; SPL CAP, splenius capitis.

Sitthinamsuwan & Nunta-aree, 2010; Taira, 2003, 2009). Additionally, considerable bleeding from the paravertebral venous plexuses adjacent to the C1 and C2 posterior rami sometimes happens intraoperatively (Braun & Richter, 2002; Taira, 2009). Other potential complications include transient occipital neuralgia which usually disappears within 3 months (Braun & Richter, 2002; Huh et al., 2005), weakness of non-dystonic muscles (Taira, 2009) caused by excessive denervation (Feely, 2003), surgical site infection (Huh et al., 2005; Münchau et al., 2001a), swallowing dysfunction (Braun & Richter, 2002; Münchau et al., 2001a, 2001b; Taira, 2009), and injury of the extradural vertebral artery located close to the C1 dorsal ramus (Braun & Richter, 2002; Taira, 2009).

4.2.2 Taira's modified method

Because of some critical disadvantages of Bertrand operation, especially C2 dysesthesia and bleeding around the C1 and C2 posterior branches, the C1-C2 procedure was modified to minimize these drawbacks (Taira & Hori, 2002; Taira et al., 2006). In Taira's method, the operation on C1 and C2 spinal nerves was adapted from extraspinal C1-C2 rhizotomy (or C1-C2 dorsal ramisectomy) in Bertrand procedure (Fig.8A) to intradural C1-C2 anterior rhizotomy (Fig.8B), while the C3 to C6 procedure is identical to that of Bertrand (Fig.8C). Therefore, the modified method is a combination of intradural C1-C2 anterior rhizotomy performed through the C1 hemilaminectomy and conventional C3-C6 posterior ramisectomy (Sitthinamsuwan & Nunta-aree, 2010; Taira, 2009).

Resection of the C1 and C2 anterior spinal nerve roots (C1-C2 anterior rhizotomy) can entirely preserve sensory function of the C2 posterior spinal nerve root, so C2 dysesthesia does not occur. Furthermore, the unilateral C1-C2 procedure does not bring about swallowing trouble. Although the efficacy of Taira's modified method in the treatment of cervical dystonia was not significantly different from that of the Bertrand procedure, the C2 sensory disturbance, operative time, and intraoperative blood loss were appreciably minimized by Taira's operation (Taira & Hori, 2001; Taira et al., 2002; Taira & Hori, 2003). Potential complications of intradural C1-C2 operation may have occurred, such as cerebrospinal fluid leak, meningitis, spinal cord injury, and spinal cord ischemia. However, all of them are preventable and avoidable.

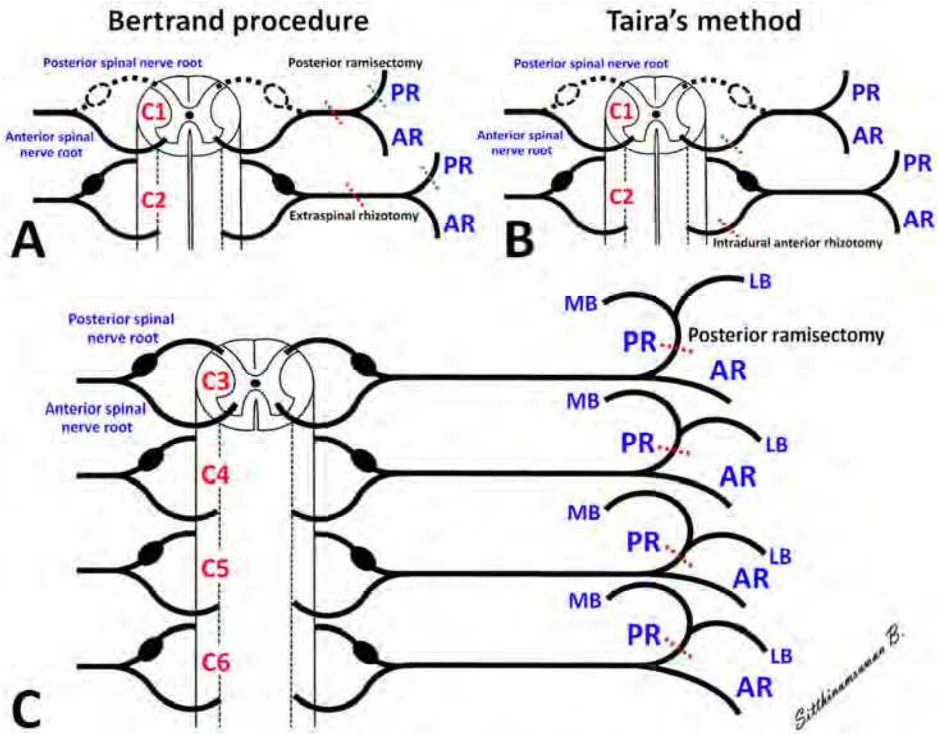

Fig. 8. A, B and C, A comparison between Bertrand procedure and Taira's method. A, C1-C2 denervation in Bertrand procedure. The C1-C2 nerves can be cut on either the spinal roots (extraspinal rhizotomy) presented by red dashed lines or posterior rami (PR) displayed by green dashed lines. B, Intradural C1-C2 anterior rhizotomy in Taira's method. The resection will be performed on the C1 and C2 anterior spinal nerve roots (red dash lines), while the C2 posterior spinal nerve root will be entirely preserved. For A and B, The C1 posterior spinal nerve root and its dorsal root ganglion are usually absent in the majority of humans. Therefore, they are presented in a dashed appearance. C, C3-C6 posterior ramisectomy is identical in both the operations.

4.3 Surgical anatomy of the accessory nerve and its peripheral branches

The accessory nerve originates from its cranial and spinal roots. After the nerve exits the posterior cranial fossa through the jugular foramen, it runs underneath the sternocleidomastoid muscle where it gives motor branches to the muscle and appears in the posterior triangle of the neck after that (Aramrattana et al., 2005; Clemente, 1985; Frank 1997; Roman 1981). In the triangle, it emerges from the posterior border of the sternocleidomastoid at the punctum nervosum (Erb's point) (Anderson et al., 2008; Aramrattana et al., 2005). There are several nerves arising from this point, including the great auricular, lesser occipital, transverse cervical, and supraclavicular nerves (Anderson et al., 2008; Aramrattana et al., 2005; Dailiana et al., 2001). From the punctum nervosum, the accessory nerve courses inferolaterally, then ramifies into numerous branches supplying the trapezius (Aramrattana et al., 2005; Clemente, 1985; Dailiana et al., 2001; Kierner et al., 2000; Roman 1981; Shiozaki et al., 2000) (Fig.9).

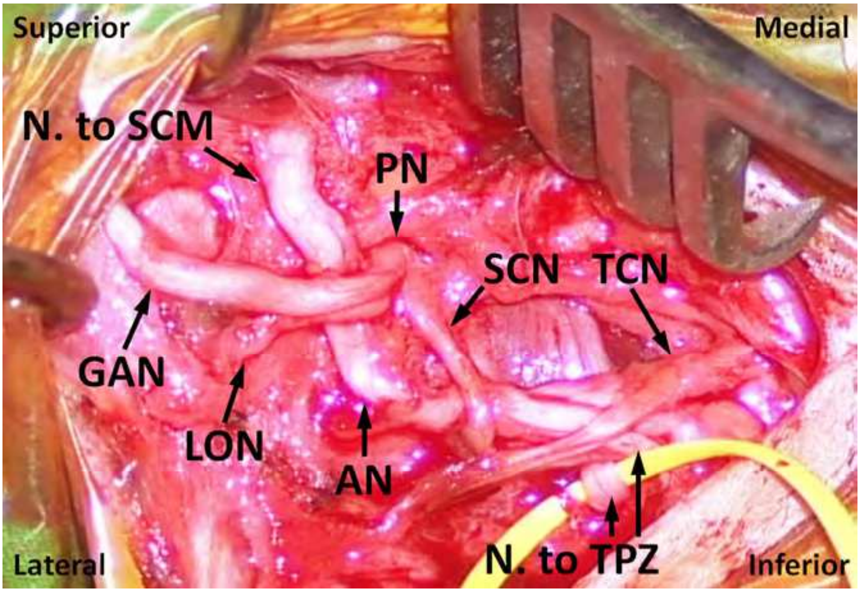

Fig. 9. The posterior cervical triangle, right side. Several nerves, including the great auricular nerve (GAN), lesser occipital nerve (LON), accessory nerve (AN), supraclavicular nerve (SCN), and transverse cervical nerve (TCN) emerge from the punctum nervosum (PN). After the accessory nerve gives nerve(s) to the sternocleidomastoid (N. to SCM), it runs inferolaterally and then terminates as nerve(s) to the trapezius (N. to TPZ).

In addition to the accessory nerve, motor branches of the cervical plexus derived from the C2-C3 anterior rami participate in innervation of the sternocleidomastoid and trapezius muscles (Aramrattana et al., 2005; Bertrand, 2004; Clemente, 1985; Dailiana et al., 2001; Pu et al., 2008; Roman 1981; Stacey et al., 1995; Zhao et al., 2006). Among the entire phalanx of nerves to both the muscles, multiple variations can be encountered during surgical exploration (Brennan et al., 2002; Brown et al., 1988; Caliot et al., 1984, 1989; Latarjet, 1948; Stacey et al., 1995; Taira, 2009) (Fig.10 and Fig.11). Knowledge of the variations is essential in accessory nerve denervation. Incomplete denervation of the sternocleidomastoid usually occurs in individuals who have hidden extra nerve supply from the cervical plexus. Failure of improvement or recurrent dystonia is occasionally due to this aberration. Furthermore, ignorance of diversity of trapezius innervation perhaps gives rise to injured trapezius nerves resulting in shoulder dysfunction.

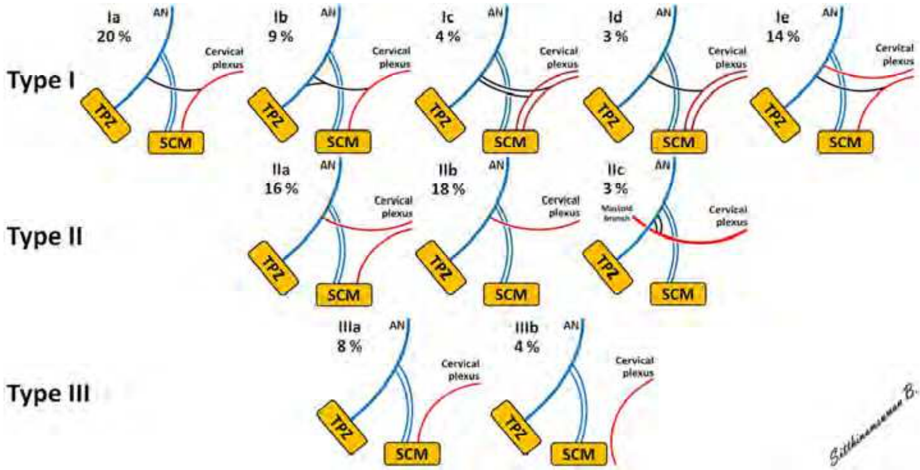

Fig. 10. Variations of the sternocleidomastoid (SCM) innervation and their frequencies in percentage. Type I, Presence of a connecting branch between the accessory nerve (AN) and cervical plexus. Type II, The accessory nerve directly connects to the cervical plexus. Type III, no connection between either of them. TPZ, trapezius. [Modified from Caliot et al., 1984].

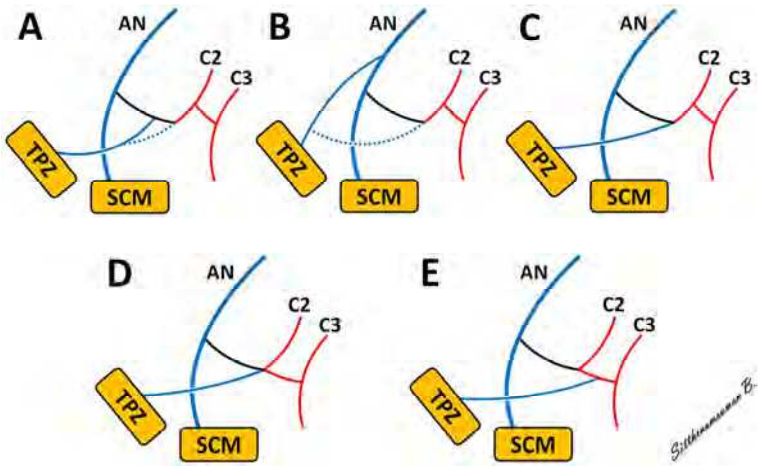

Fig. 11. Variation of the nerve to the trapezius (TPZ). A, The nerve originates from a connecting branch between the accessory nerve (AN) and anterior ramus of the C2 spinal nerve (C2). A direct branch from the C2 anterior rami (dotted line) may participate in the supply. B, The accessory nerve gives a direct branch to supply the trapezius. An additional twig perhaps comes from the C2 anterior ramus to join the main supply (dotted line). C, The trapezius is innervated by the nerve arising from the junction between the C2 anterior ramus and a connecting branch from the accessory nerve. D, The nerve emerges from the union of the connecting branches of the accessory nerve, C2, and C3 anterior rami (C3). E, A connection between C2 and C3 anterior rami gives the nerve supplying the trapezius muscle. SCM, sternocleidomastoid. [Modified from Latarjet, 1948].

4.4 Selective denervation of the sternocleidomastoid muscle

Selective resection of nerve to the sternocleidomastoid with sparing of the trapezius nerve is commonly used in the treatment of torticollis and laterocollis. It is one of two main parts of Bertrand procedure. In our viewpoint, we considered sternocleidomastoid denervation on the contralateral side of posterior cervical muscle denervation in all patients with torticollis. In addition, we used the ipsilateral procedure in some laterocollic cases, particularly in patients with absence of shoulder elevation, which probably indicated hyperactivity of the sternocleidomastoid rather than that of the levator scapulae. The denervation can be done through a small incision along the posterior boundary of the sternocleidomastoid muscle (Fig.12A). Medial retraction of the sternocleidomastoid is helpful in visualization of the nerve. The nerve is often seen underneath the retracted muscle (Fig.12B).

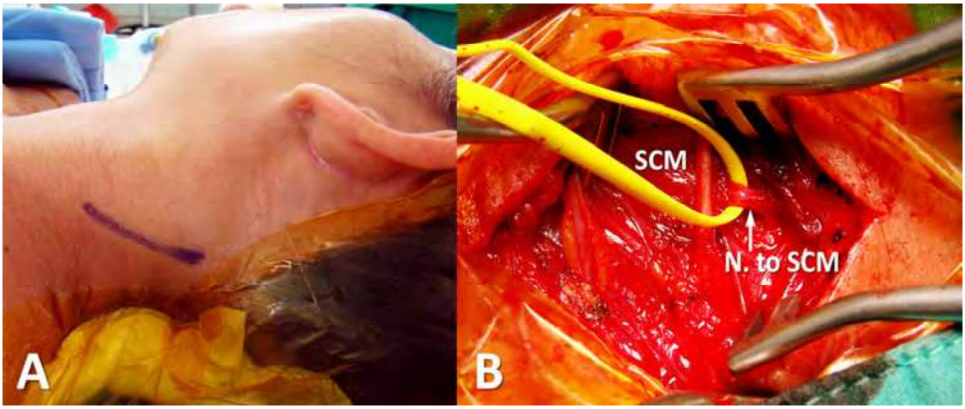

Fig. 12. Selective denervation of the left sternocleidomastoid (SCM). A, A small incision (blue line) along the posterior margin of the sternocleidomastoid. B, Operative exposure of nerve to the sternocleidomastoid (N. to SCM). It can be clearly found when the muscle is medially displaced.

Electrical stimulation of the correct nerve absolutely reveals contraction of the sternocleidomastoid without movement of the trapezius. On the other hand, isolated trapezius contraction indicates stimulation of the trapezius nerve which is inaccurate. If contraction occurs on both the muscles, that is a too proximal position. Besides, the additional nerve supply from the cervical plexus should be investigated and then sectioned. The potential complications are injury of nerve to the trapezius (Albanese et al., 2006; Braun & Richter, 1994, 2002; Taira, 2009) and numbness in the retro-auricular area caused by injury or excessive retraction of the great auricular nerve during the operation (Braun & Richter, 1994).

4.5 Anatomy of the levator scapulae and its nerve supply

The levator scapulae is the key muscle in emergence of laterocollis (Anderson et al., 2008; Taira et al., 2003), particularly when the lateral neck deviation is accompanied by elevation of the ipsilateral scapula. It extends from transverse processes of the 1st to 4th cervical vertebrae to insert at the medial aspect of the upper scapular border superior to the scapular spine (Roman, 1981) (Fig.13A). Contraction of the muscle brings about lateral inclination of the ipsilateral head and neck in the coronal plane together with upheaval of the shoulder on the same side (Clemente, 1985; Roman, 1981; Taira et al. 2003) (Fig.13B). Its major nerve supply originates from C3, C4, and C5 anterior rami. The twigs from C3-C4 nerve roots pass underneath the sternocleidomastoid and then enter the anteromedial aspect of the levator muscle. The dorsal scapular nerve arising from the C5 anterior ramus also participates in the innervation of the levator muscle through its inferomedial surface (Anderson et al., 2008; Clemente, 1985; Roman, 1981; Taira, 2009).

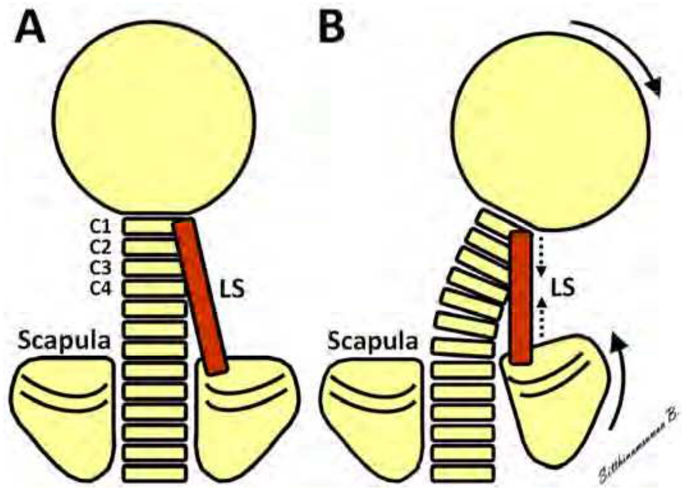

Fig. 13. Functional anatomy of the levator scapulae muscle. A, The muscle originates from the upper four cervical spines, then extends inferolaterally to the superior border of the scapula. B, Its main action consists of neck lateral deviation as well as shoulder elevation.

4.6 Levator scapulae muscle denervation

The operation is mainly indicated in laterocollic patients (Anderson et al., 2008) with marked shoulder elevation and minimal head rotation (Taira, 2009). The ascending shoulder points to the hyperactive levator muscle (Hernesniemi & Keränen, 1990; Taira & Hori, 2001; Taira, 2009). Importantly, noting palpable tense levator scapulae in the posterior cervical triangle is helpful in the diagnosis (Taira, 2009). The surgical incision is identical to that of the sternocleidomastoid denervation. The C3-C4 muscular branches can be encountered by using electrical nerve stimulator and then cutting on the anteromedial surface of the levator muscle (Fig.14). The further supply coming from the dorsal scapular nerve should be explored and eventually ablated. Care should be taken to preserve the adjacent phrenic nerve (Taira et al., 2003) and upper part of the brachial plexus.

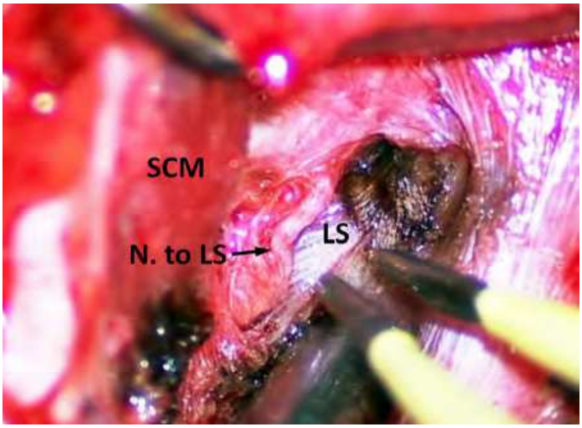

Fig. 14. Microsurgical exposure of the levator scapulae (LS) and its nerve supply (N. to LS) in the left posterior cervical triangle. The sternocleidomastoid (SCM) is retracted anteriorly. Nerve to the levator muscle can be identified on the anterior aspect of the innervated muscle.

4.7 Intraoperative electrical nerve stimulation

Aside from knowledge in the surgical anatomy, identification of accurate nerves by using intraoperative electrical nerve stimulator is very crucial in selective peripheral denervation for cervical dystonia. Intraoperative nerve stimulation has many benefits. It assists in exploration of nerves in the operative field (Brin & Benabou, 1999), in discrimination between motor and sensory nerves, and, importantly, defines muscle topography supplied by electrically stimulated nerve. Sensory nerve must be distinguished from motor nerve. The former has to be routinely preserved as much as possible to avoid neuropathic pain caused by injured or sectioned sensory nerve. Stimulation of motor nerve absolutely elicits contraction of the corresponding muscle (Ondo & Krauss, 2004) whereas there is nothing which occurs when sensory nerve is stimulated. Determination of innervation topography is valuable in selective nerve section. It can tell us which ones should be cut and left (Brin & Benabou, 1999; Sitthinamsuwan et al., 2010c). This strategy always results in the absence of adverse events caused by wrong nerve resection and unnecessary denervation (Sitthinamsuwan et al., 2010c). In utilization of the intraoperative electrical stimulator, short-acting muscle relaxants can be administered only for induction of general anesthesia and must be prohibited after that (Ondo & Krauss, 2004; Taira, 2009).

In posterior cervical muscle denervation, stimulation on each posterior cervical ramus gives rise to segmental contraction of the corresponding muscle. For instance, stimulation of the C2 posterior branch leads to vigorous contraction of the upper fibers of the splenius capitis, while movement of its lower portion is always elicited by electrical stimulation of the C5 or C6 posterior ramus. As discussed in denervation of the sternocleidomastoid, too proximal stimulation of the accessory nerve brings about concurrent contraction of both muscles innervated by the nerve. Isolated movement of either the sternocleidomastoid or trapezius indicates separated stimulation on the sternocleidomastoid or trapezius nerve, respectively. Furthermore, direct stimulation of nerve to the levator scapulae simply reveals contraction of the muscle. If movement of the diaphragm also appears, that means we are very close to the phrenic nerve. In the same manner, if the levator scapulae and rotator cuffs of the shoulder or pectoral muscles contract simultaneously during stimulation of the dorsal scapular nerve, this phenomenon indicates that the present location is too closely adjacent to the C5 spinal root or upper trunk of the brachial plexus.

4.8 Conclusion of the nerve supply

The nerves which contribute to the innervation of cervical dystonic muscles are summarized in Table 3 (Anderson et al., 2008; Aramrattana et al., 2005; Bertrand, 2004; Clemente, 1985; Dailiana et al., 2001; Frank et al., 1997; Kierner et al., 2000; Pu et al., 2008; Roman, 1981; Stacey et al., 1995; Taira, 2009; Zhao et al., 2006).

Cervical muscles	Nerve supply
Suboccipital muscles (rectus capitis posterior major and minor, obliguus superior capitis and obliguus inferior capitis)	Posterior rami of C1-C2 spinal nerves
Semispinalis capitis	Posterior rami of C1-C8 spinal nerves
Semispinalis cervicis	Posterior rami of C1-C8 spinal nerves
Splenius capitis	Posterior rami of C2-C6 spinal nerves
Longissimus cervicis	Posterior rami of C6-C8 spinal nerves
Levator scapulae	Anterior rami of C3-C4 spinal nerves Dorsal scapular nerve (from anterior ramus of C5 spinal nerve)
Trapezius	Accessory nerve Anterior rami of C2-C3 spinal nerves
Sternocleidomastoid	Accessory nerve Anterior rami of C2-C3 spinal nerves

Table 3. The muscles in the neck region associated with cervical dystonia and their nerve supply

4.9 Alternatives in selective peripheral denervation

In selective peripheral denervation, the procedure should be tailored according to the presenting dystonic forms (Sitthinamsuwan et al., 2010b). Surgical options for cervical dystonia are listed in Table 4 (Bertrand, 1993; Braun & Richter, 2002; Brin & Benabou, 1999; Chen et al., 2000; Huh et al., 2005, 2010; Münchau et al., 2001a; Taira et al., 2003). Selective peripheral denervation is not a good alternative for anterocollis because extensive bilateral denervation of both superficial and deep anterior cervical muscles can lead to significant disabling anterior neck muscle paresis and swallowing dysfunction. Furthermore, the operation is usually not effective in the treatment of anterocollis and complex cervical dystonia. Therefore, pallidal deep brain stimulation should be considered as the primary surgical therapy for such kinds of cervical dystonia.

Dystonic pattern	Common option in selective denervation
Torticollis	Selective C1-C6 denervation of the posterior cervical paraspinal muscles ipsilateral to the rotating head with contralateral sternocleidomastoid denervation
Retrocollis	Selective C1-C6 denervation of the bilateral posterior cervical paraspinal muscles; nevertheless, the unilateral C6 posterior ramus should be carefully preserved Selective denervation of the upper trapezius may be indicated either unilaterally or bilaterally in patients who have dystonia of this muscle
Laterocollis	Selective C1-C6 denervation of the posterior cervical muscles and levator scapula on the same side of the inclination Selective denervation of the ipsilateral sternocleidomastoid may be indicated in patients who have dystonia of this muscle
Torticollis + retrocollis	Bilateral posterior cervical muscle denervation (C1-C6 denervation on the ipsilateral side of the turning face with contralateral C1 - C4 or C5 denervation) plus contralateral sternocleidomastoid denervation If indicated, selective denervation of the upper trapezius should be done either unilaterally or bilaterally
Retrocollis + laterocollis	Bilateral posterior cervical muscle denervation (C1 - C6 denervation on the ipsilateral side of the tilting head with contralateral C1 - C4 or C5 denervation) plus ipsilateral levator scapulae denervation If indicated, the sternocleidomastoid ipsilateral to the tilting head should be denervated If indicated, selective denervation of the upper trapezius should be done either unilaterally or bilaterally
Anterocollis	Is not a good candidate for selective denervation Should be managed surgically by pallidal deep brain stimulation
Complex cervical dystonia	
Alternatives in C1-C6 denervation of the posterior cervical muscles	a. Extraspinal C1-C2 rhizotomy plus C3-C6 posterior ramisectomy (original Bertrand's denervation) b. Selective C1-C6 posterior ramisectomy c. Intradural C1-C2 anterior rhizotomy plus C3-C6 posterior ramisectomy (Taira's modified method)

Table 4. Alternatives in peripheral denervation for various patterns of cervical dystonia

4.10 Combined operative procedures

Our treatment of complex cervical dystonia and idiopathic generalized dystonia by using bilateral pallidal deep brain stimulation indicates that all of them dramatically respond to the operation. However, a few cases still had some residual cervical dystonia even though we attempted to adjust their implanted neurostimulators optimally. In such patients, we decided to add selective peripheral denervation to the muscles which have residual hypertonia. Postoperative improvement was encountered in all our cases who underwent the combined procedures. In summary, if the satisfactory outcome cannot be fulfilled by deep brain stimulation alone, selective peripheral denervation (or even selective muscle resection) is a good further surgical option in the treatment of refractory complex cervical dystonia. A demonstration of a case on whom we operated by using the combined procedures is presented in Fig.15.

5. Surgical outcome

By collecting surgical outcomes of selective denervation for cervical dystonia, the numerous studies revealed satisfactory results with minimal complications. Nonetheless, various methods in measure of outcome were utilized. Some of them were unvalidated and employed subjective methods whereas the remaining studies used widely accepted and validated measure tools, such as the TWSTRS or Tsui score. Overall therapeutic outcomes of selective peripheral denervation are displayed in Table 5 (Bertrand, 1993; Braun et al., 2002; Chen et al., 2000; Cohen-Gadol et al., 2003; Huh et al., 2005, 2010; Jang et al., 2005; Meyer, 2001; Münchau et al., 2001a; Nunta-aree et al., 2010a; Sitthinamsuwan et al., 2010b; Taira & Hori; 2003; Taira et al., 2003).

Fig. 15. A female patient with idiopathic generalized dystonia who underwent combined pallidal deep brain stimulation and selective peripheral denervation. A, Preoperative image reveals severe disabling generalized dystonia including mobile cervical dystonia. B, After the deep brain stimulation, her generalized and complex cervical dystonia was markedly improved. She could return to sitting and walking again. However, residual complex cervical dystonia (mobile left torticollis and retrocollis) was persistent even though we adjusted the implanted neurostimulator to achieve maximal benefit. Hence, we decided to denervate the remaining dystonic muscles. C, After multifocal selective denervation of the cervical muscles (left C1 - C6 and right C1 - C4 posterior ramisectomy, right sternocleidomastoid, and bilateral upper trapezius denervation), the residual dystonia was dramatically improved without complication.

Study	Outcome	Complication
Bertrand, 1993 n = 260 cases Age 29 - 61 years Follow-up period 64 cases: more than 10 years 167 cases: more than 5 years Outcome measure: unvalidated outcome scale	Excellent (no detectable abnormal movements): 40% Very good (slight deviation or slight residual movements): 48% Fair (appreciable amount of residual abnormal movements): 10% Poor (no improvement or worse): 1% Overall residual dystonia: 12%	No death Abscess: 1 patient Sensory loss in the distribution of the greater occipital nerve: unspecified number of cases Tic-like pain: 3 patients
Chen et al., 2000 The operation included selective peripheral denervation and myotomy n = 207 cases Mean age 39 years Follow-up 2 - 29 years Outcome measure: unvalidated outcome scale	Excellent (no detectable abnormal movements, normal movement of neck preserved): 70.5% Very good (slight deviation or slight residual movements): 7.4% Fair (appreciable amount of residual abnormal movements): 9.2% Poor (no improvement or worse): 2.9%	No death Sensory loss in distribution of the greater occipital nerve: most patients
Meyer, 2001 n = 30 cases Median age 55 years Median follow-up 26 months Outcome measure: - The severity score component of the TWSTRS - The scales for activities of daily living (ADL), whole person impairment, adverse life style effects and degree of incapacity	Overall improvement of the TWSTRS: 59% ADL score improvement: 90% Improvement of whole person impairment score: 59% Life style score improvement: 34% Improvement of incapacity score: 50%	Not mentioned
Münchau et al., 2001a n = 37 cases Mean age 50 years Mean follow-up 16.7 years Outcome measure: - The TWSTRS - Head tremor severity - Maximum degree of head rotation and head tilt - Self-assessed outcome - Psychological assessment	At 1-year follow-up Functional improvement: 68% of patients Mean total TWSTRS improvement: 30% Severity score reduction: 20% Disability score reduction: 40% Pain score reduction: 30% Head tremor severity did not change Self assessment outcome Comparable benefit of surgery and the past best response to botulinum toxin: 10% of patients Surgery was superior: 67% of patients Surgery was worse: 23% of patients Improvement in some psychological measures	No death Wound complication: 1 patient Progressive dystonia: 1 patient Transient imbalance: 3 patients Dysesthesia in the denervated posterior cervical segments: all patients Transient trapezius paresis: 1 patient Dysphagia: 7 patients Deterioration of dysphagia: 5 patients

Study	Outcome	Complication
Braun et al., 2002 n = 140 cases Mean age 39.7 years Mean follow-up 32.8 months Outcome measure: subjective assessment by the patients self-estimate questionaire	Satisfactory: 73% Complete relief: 13%, Significant improvement: 36% Moderate improvement: 24% Ineffective: 27% Minor relief: 14% No improvement: 14% Recurrent dystonia: 11%	No death Hematoma in the anterior neck: 3 patients Transient dysphagia: 4 patients Sensory deficit in the area of the greater occipital nerve: all patients Injury of trapezius branch of the accessory nerve: 2 patients
Taira & Hori, 2003 n = 82 cases Age: not mentioned Follow-up 3 months Outcome measure: Tsui score	Mean Tsui score improvement Group A (44 patients who underwent the modified Taira's procedure): 85% Group B (38 patients who underwent the traditional Bertrand procedure): 86.4 %	No death Sensory deficit in C2 dermatome Group A: 3 patients Group B: all (38) patients
Taira et al., 2003 n = 10 cases Mean age 34.8 years Mean follow-up 29.4 months Outcome measure: Tsui score	Mean Tsui score improvement: 88% Excellent: 40 % Good: 60 %	No death Transient C3 or C4 dysesthesia: 5 patients
Cohen-Gadol et al., 2003 n = 168 cases Mean age 53.4 years Mean follow-up 3.4 years in 130 cases Outcome measure: unvalidated outcome scale	At the 3-month follow-up Moderate to excellent improvement: 77% Pain improvement 81 % Long-term follow-up (mean 3.4 years) Moderate to excellent improvement: 70%	Death due to respiratory arrest: 1 patient Persistent C2 dysesthesia: 3 patients Slight shoulder weakness: 3 patients Wound infection: 1 patient
Jang et al., 2005 n = 5 cases Mean age 43.75 years Follow-up 3 months Outcome measure: - The TWSTRS - Cervical Dystonia Severity Scale (CDSS) - Visual Analogue Scale (VAS)	Mean total TWSTRS improvement: 76.5% CDSS improvement: 48.7% VAS improvement: 77.6%	No death or complication
Huh et al., 2005 n = 10 cases Mean age 52.4 years Mean follow-up 36 months Outcome measure: identical to that of the original Bertrand's study	Excellent :50% Good: 40% Fair: 10%	No death Wound infection: 2 patients Delirium: 1 patient Generalized weakness: 1 patient Transient neuralgia: unspecified number of cases

Study	Outcome	Complication
Huh et al., 2010 n = 24 cases Mean age 46.6 years Mean follow-up 29.5 months Outcome measure: - The TWSTRS - Subjective assessment by the patients	Mean total TWSTRS improvement In 16 patients who underwent selective peripheral denervation: 59% In 7 patients who underwent pallidal deep brain stimulation: 64.1% In 1 patient who underwent combined surgery: 92.5% The subjective result assessed by the patients Selective denervation group: excellent 25%, good 62.5%, and fair 12.5% Deep brain stimulation group (including a patient who underwent combined operation): excellent 25 %, good 62.5 %, and fair 12.5 %	No death Wound infection: 2 patients Occipital neuralgia: 3 patients Delirium: 1 patient Venous air embolism: 1 patient
Nunta-aree et al., 2010a n = 6 cases Age 24 - 62 years Mean follow-up 29.7 months Outcome measure: Tsui score	Mean Tsui score improvement: 70%	No death or complication
Sitthinamsuwan et al., 2010b Combined use of ablative neurosurgical operations for intractable spastic and dystonic cerebral palsy Single case report Age 27 years Follow-up period 12 months Outcome measure: - Unvalidated outcome scale for cervical dystonia (assessed by clinical observation and physical examination) - Modified Ashworth Scale (MAS) for spasticity	Disappearance of cervical dystonia following unilateral C1-C6 posterior ramisectomy Markedly improved neck control Improved swallowing Marked improvement of generalized spasticity Improved sitting balance and posture	No death or complication

Table 5. Therapeutic outcome of selective peripheral denervation in the treatment of cervical dystonia

6. Conclusion

Various surgical procedures should be considered in cervically dystonic individuals who do not respond to the conventional treatment. Among them, selective peripheral denervation usually yields a satisfactory result and has been one of the most popularly used operations for the disorder. It is mainly indicated in almost types of cervical dystonia, excluding anterocollis and complex patterns. The surgical planning and tailored resection of the nerve should be relied on the individual dystonic pattern. Good candidate selection, knowledge of the relevant anatomy, surgical skills in nerve exploration and precise identification are very significant in the operation through which they will lead to an excellent therapeutic outcome and avoidance of potential adverse effects.

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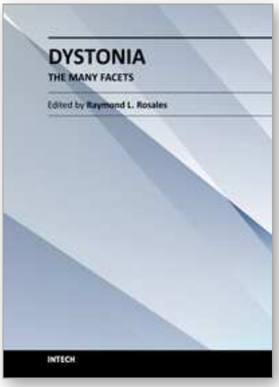

Dystonia - The Many Facets
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Dystonia has many facets, and among those, this book commences with the increasingly associated genes identified, including a construct on how biology interacts with the dystonia genesis. The clinical phenomenology of dystonia as approached in the book is interesting because, not only were the cervical, oromandibular/lingual/laryngeal, task-specific and secondary dystonias dealt with individually, but that the associated features such as parkinsonism, tremors and spasticity were also separately presented. Advances in dystonia management followed, and they ranged from dopaminergic therapy, chemodenervation, surgical approaches and rehabilitation, effectively complementing the approach in dystonia at the clinics. A timely critical pathophysiologic review, including the muscle spindle involvement in dystonia, is highlighted at the book's end.