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CLINICAL ARTICLE - FUNCTIONAL

Denervation and myotomy of muscles of the omotrapezoid triangle of the neck improve the outcomes of surgical treatment of laterocollis and torticollis subtypes of spasmodic torticollis: 58 case analysis

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Abstract
Background The main objective of this study was to analyze the outcomes of denervation and myotomy of the muscles of the omotrapezoid triangle of the neck in the treatment of 58 patients with the laterocollis and torticollis subtypes of spasmodic torticollis.
Methods Fifty-eight patients with the laterocollis and torticollis subtypes of spasmodic torticollis underwent 135 staged microsurgical denervations, including 25 denervation and myotomy procedures on the dystonic muscles of the omotrapezoid triangle (Tretyak's procedure). The outcome evaluation was conducted via neurological examination and the Toronto Western Spasmodic Torticollis Rating Scale (Severity subscale).
Results Tretyak's procedure allowed us to improve the outcomes of surgical treatment of the latero- and torticollis subtypes of spasmodic torticollis. Ninety-two percent of patients who underwent the denervation of the muscles of the omotrapezoid triangle moved to the group with lower ST severity—predominantly to the group with mild severity (21 patients out of 25). Tretyak's procedure appeared to be effective in 100 % of patients with the torticollis subtype of ST (15 patients out of 15) and in 80 % of patients with the laterocollis subtype of ST (8 patients out of 10).
Conclusions Tretyak's procedure appears to be an excellent additional surgical procedure in terms of improvement of the outcomes of the "classic" Bertrand microsurgical denervation of the muscles of the neck in patients with the latero- and torticollis subtypes of spasmodic torticollis; staging of surgical denervation of muscles of the neck in the treatment of patients with the latero- and torticollis subtypes of spasmodic torticollis allows the surgeon to precisely evaluate the outcomes of previously conducted procedures, individualize the surgical approach by providing the necessary time and space to create a well-defined plan and thoroughly define the aims of further surgical denervation.

Keywords Spasmodic torticollis · Laterocollis subtype · Torticollis subtype · Microsurgical denervation

Inroduction

The denervation of the muscles involved in head and neck rotation or flexion in non-complicated cases of spasmodic torticollis (ST) is considered the primary procedure by the majority of surgeons [4]. Many techniques have been proposed throughout the years, but the main aim remains unchanged—in all latero- or torticollis subtypes of ST cases, both the posterior cervical paravertebral muscles and sternocleidomastoid muscle should be denervated [4]. Denervation of the sternocleidomastoid muscle, or the Buyalsky procedure, seems to be quite simple, the complications are known, and the anatomical variations of sternocleidomastoid muscle innervation are well studied [4]. The denervation of posterior cervical paravertebral muscles, according to modern reviews, implies surgical ablation of the principal origins of their innervation, the C1–C6 posterior rami [2]. Nowadays, two procedures are widely used to ensure the proper denervation of the C1–C6 posterior rami: the classic Bertrand's procedure and its Taira's modification [2, 5]. The only difference between the two of them is the following: the C1–C2 posterior rami are meant to be transected

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extradurally or within the intradural space. Some surgeons prefer Taira's modification, but several severe complications may occur: cerebral fluid leakage, infection, injury of the cervical spine, etc. [4]. On the other hand, the supporters of Bertrand's procedure claim that after surgery the outcomes are equal, but the risk of severe or even life-threatening complications is minimized [4].

Precise anatomical studies, analysis of outcomes and surgical failures have marked the main pitfalls of denervation surgeries of the posterior cervical paravertebral muscles [1, 4]: (1) features of m. semispinalis capitis innervation; (2) features of m. splenius capitis innervation; (3) features of m. levator scapulae innervation. Furthermore, recent studies point out the leading role of the m. levator scapulae in residual ST or its recurrence [1]. According to Anderson et al. [1], the main origins of m. levator scapulae innervation are branches from the anterior rami of C3–C5, wherein unilateral contraction of m. levator scapulae innervation leads to the head tilt associated with shoulder elevation.

However, the role of m. semispinalis capitis and m. splenius capitis innervation remains underestimated: reviews have pointed out some features of their innervation [4], although the precise techniques for their denervation remain unclear. According Sitthinamsuwan et al. [4], the major features of m. semispinalis capitis and m. splenius capitis innervation are the following: the posterior rami of C3–C4, and sometimes C2 and C5, divide into the lateral and medial branches; both the medial and lateral branches innervate the m. semispinalis capitis; the m. splenius capitis is innervated by the lateral branch (Fig. 1). The major pitfalls, according to Sitthinamsuwan et al. [4], are: the medial and lateral branches of posterior rami run on the opposite surfaces of the m. semispinalis capitis; they reach the belly of the m. semispinalis capitis and m. splenius capitis anteriorly to surgeon's viewpoint, right behind the bellies of the above-mentioned muscles. They are thus difficult to reach without their transection and sometimes wide resection. During the classical Bertrand procedure the posterior rami of C3–C4 should be identified once they arise from under the vertebral lamina. It is much easier when they arise as a common trunk, but sometimes the lateral branch of C3, a key nerve to the m. semispinalis capitis and m. splenius capitis, remains hidden; thus, the origins of the m. semispinalis capitis and m. splenius capitis still exist. We agree that the process of dissecting and exploring the later branch of C3 is a matter of surgeon experience; nevertheless, sometimes it is difficult to find.

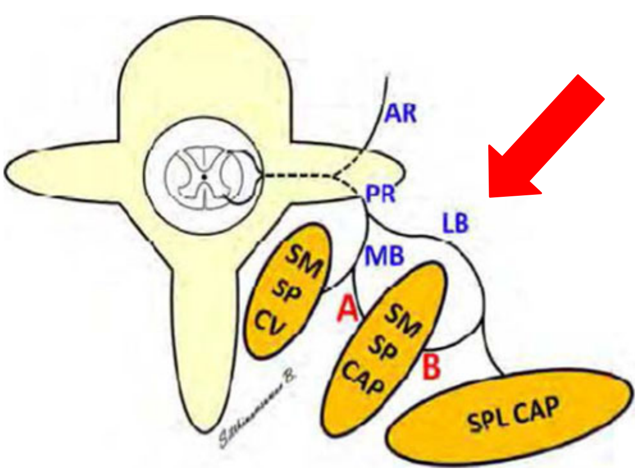

Fig. 1 Features of innervation of the m. semispinalis capitis (SM SP CAP) and m. splenius capitis (SPL CAP). **a** and **b** The muscular branches arising from the medial branch (MB) and lateral branch (LB) of the posterior cervical rami (PR); AR, anterior cervical rami (by Sitthinamsuwan and Nunta-Aree [4]); the red arrow indicates the direction of exposure during Tretyak's procedure

We carefully and precisely analyzed the available literature data, our own experience, and the advantages and disadvantages of the methodology for the already existing surgical procedures and decided to include a new m. semispinalis capitis, m. splenius capitis and m. levator scapulae denervation technique to treat patients with residual or recurrent spasmodic torticollis in addition to the classical surgery known as Bertrand's procedure. We call it denervation and myotomy of the muscles of the omotrapezoid triangle or Tretyak's procedure, developed by the Ukrainian neurosurgeon Ihor B. Tretyak in 2000–2002. Tretyak's thorough search for the neurotizers in the cervical area in order to restore the function of muscles of the shoulder girdle in cases of different types of brachial plexus palsy allowed him to study the detailed anatomy of the muscles of the neck, their origins and features of innervation and refine the surgical exposures. Eventually, Tretyak designed and was the first to introduce the methodology of denervation of the muscles of the omotrapezoid triangle into clinical practice to treat patients with residual or recurrent spasmodic torticollis.

To clarify the features of Tretyak's procedure and to help understand the exact localization of the lateral branch of the C3 posterior rami, we provide the scheme of Sitthinamsuwan et al. [4] in Fig. 1; the red arrow indicates the direction of "attack" (exposure), which allows the surgeon to explore and ablate the lateral branch of the C3 posterior rami.

During Tretyak's procedure, the origins of innervation of the m. semispinalis capitis and m. splenius capitis, lateral branches of the posterior rami (predominantly C3–C4), are exposed in the upper part of the lateral triangle of the neck, the omotrapezoid triangle, bordered by the m. trapezius, omohyoid mucle and posterior margin of the sternocleidomastoid muscle (Fig. 2).

Careful step-by-step dissection of the underlying structures is applied. First, during Tretyak's procedure, the borders that circumscribe the placement of the lateral branches of the C3 posterior rami are identified (Fig. 3). During the exposure, extra attention should be given to the branch of the accessory nerve (coming under the posterior border of the sternocleidomastoid muscle), which innervates the m. trapezius, because it can be easily

Fig. 2 Tretyak's procedure: the exposure (the skin incision is outlined in green)

damaged and provoke an additional severe neurological deficit in the postoperative period.

The lateral branch of the C3 posterior rami that penetrate the m. semispinalis capitis and m. splenius capitis complex is identified by means of careful dissection of the intermuscular spaces within the bottom of the omotrapezoid triangle posteriorly to the cervical vertebral facets. The dissection is supported by gentle electrical stimulation of the identified neural branches. The principal aim is to identify the branches whose stimulation leads to contraction of the m. semispinalis capitis and m. splenius capitis (Fig. 4). Extra attention should be given to the greater occipital nerve, the branch of the C2 posterior rami, during the dissection. The greater occipital nerve, preserved during Bertrand's procedure, can be easily damaged, which could provoke the emergence of occipital neuralgia, painful dysesthesia, etc., in the postoperative period.

Once the lateral branch of the C3 posterior rami has been identified (Fig. 5a), transection of the m. semispinalis capitis and m. splenius capitis complex is performed. The muscle complex is then gently abducted so that the precise point where the lateral branch of the C3 posterior rami penetrates the muscles becomes most visible (Fig. 5b). We prefer to

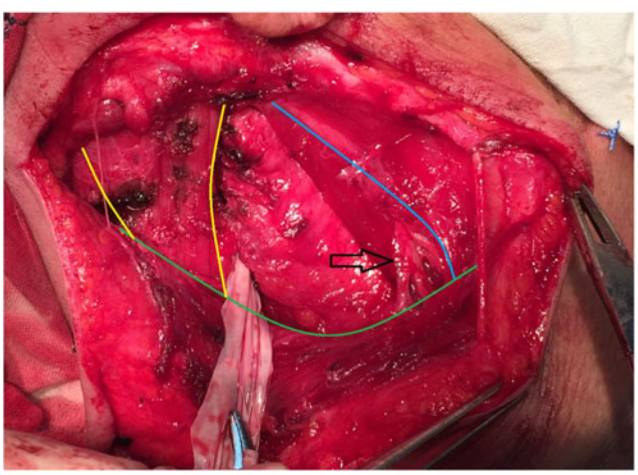

Fig. 3 Tretyak's procedure: the exposure (the posterior border of the sternocleidomastoid muscle is outlined in *blue*, the anterior border of the m. trapezius is outlined in *green*, borders of the m. splenius capitis are outlined in *yellow*, and the arrow indicates the branch of the accessory nerve to the m. trapezius)

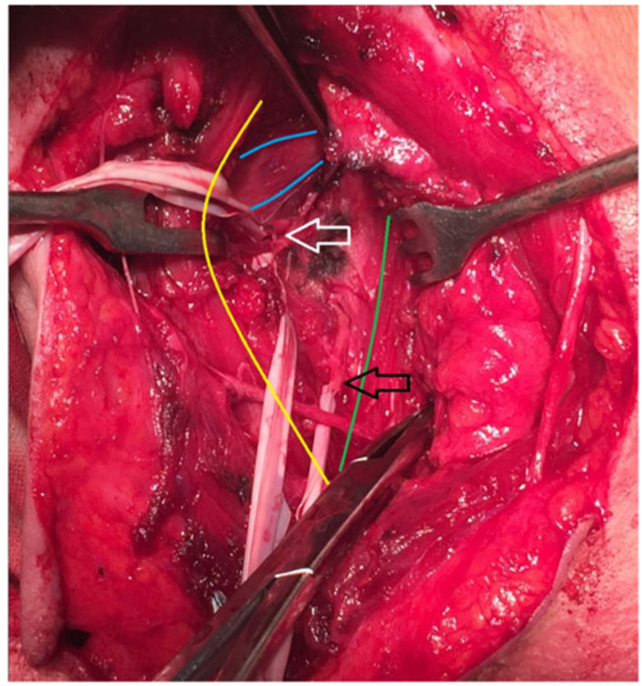

Fig. 4 Tretyak's procedure: the identification (anterior border of the m. splenius capitis is outlined in *yellow*, the posterior border of the m. longissimus capitis is outlined in *green*, and the borders of the m. obliquus capitis inferior are outlined in *blue*. The white arrow indicates the greater occipital nerve; the black arrow indicates the lateral branch of C3, which penetrates the m. splenius capitis)

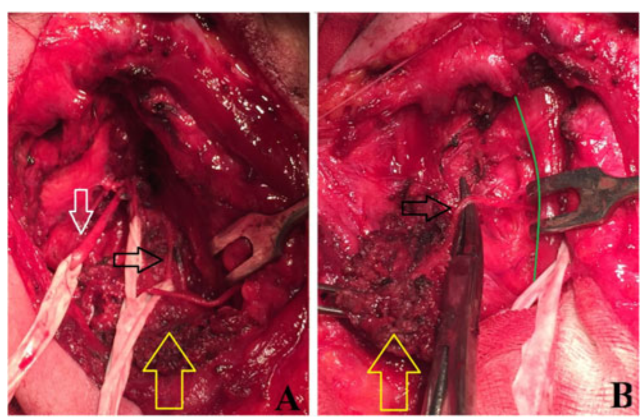

Fig. 5 Tretyak's procedure: the denervation and muscle resection (**a** The *white arrow* indicates the preserved greater occipital nerve; the yellow arrow indicates the transected and resected m. semispinalis capitis and m. splenius capitis complex; the black arrow indicates the lateral branch of C3, which penetrates the m. semispinalis capitis and m. splenius capitis complex. **b** The posterior border of the m. longissimus capitis is outlined in *green*; the yellow arrow indicates the transected and resected m. semispinalis capitis and m. splenius capitis complex; the black arrow indicates the lateral branch of C3, which penetrates the m. semispinalis capitis and m. splenius capitis complex)

apply wide resection of the m. semispinalis capitis and m. splenius capitis during the procedure; however we agree that this subject still remains a matter of discussion [3]. The nerve is then transected and widely resected, and the stumps are coagulated to prevent the possibility of accidental reinnervation.

Additionally, during Tretyak's procedure, the adjacent muscles of the neck (m. longissimus capitis and cervicis, m. levator scapulae, etc.), if indicated according to the preoperative electrophysiological and clinical findings, could be transected, as the exposure was designed to provide a wide overview of the adjoining anatomical structures.

Methods and materials

Fifty-eight patients with ST were enrolled into a single-center, long-term observational study in our department from 2002 to 2014. Among them were 26 patients with the laterocollis subtype and 32 patients with the torticollis subtype of ST (Table 1).

The inclusion criteria were: (1) all pure, non-complicated cases of ST; (2) absence of brain lesions (confirmed by MRI); (3) absence of severe deformity of the cervical spine (confirmed by X-ray); (4) absence of systemic dystonic diseases; (5) general health status compatible with two- or three-stage surgical interventions.

Twenty-four patients received botulinum toxin (type A) therapy with no benefit or a mild/short-lasting effect. The median age of patients was 46 years (29 to 72 years).

During all phases of study, initial and follow-up, patients were carefully examined by the surgeon (during the examination the subtype of ST was defined and "key" muscles were identified). EMG data provided additional information about the dystonic status of key muscles.

All 58 patients underwent staged selective microsurgical denervation of the muscles of the neck (two-stage surgery): denervation of the sternocleidomastoid muscle, first stage; denervation of the posterior cervical paravertebral muscles, second stage.

Twenty-five patients who showed residual signs of ST during the analysis of the outcomes of the two-stage surgery, which were confirmed by EMG data, underwent Tretyak's procedure—selective denervation and myotomy of the muscles of the omotrapezoid triangle. The third stage included 10 patients with the laterocollis subtype of ST and 15 patients with the torticollis subtype.

The follow-up period was divided into two phases: phase 1, the outcomes were evaluated after two-stage surgery (Byalskyy procedure followed by Bertrand's procedure); phase 2, the outcomes were evaluated among patients who underwent three-stage surgery (after Tretyak's procedure) and among those who did not.

During the evaluation of the initial TWSTRS scores (Toronto Western Spasmodic Torticollis Rating Scale) and phase 1/phase 2 TWSTRS scores, we utilized only the Severity subscale of the TWSTRS. All patients were initially divided into three groups according to the Severity subscale (0–10 points, mild severity; 11–25 points, moderate severity; 26–35 points, severe ST).

The protocol and participation consents were reviewed and approved by Ethics Committee of The State institution "Institute of Neurosurgery named after acad. A.P. Romodanov of the National Academy of Medical Sciences of Ukraine" (Kiev, Ukraine) and were in accordance with the 1964 Helsinki Declaration. All patients voluntarily participated in this study and provided written informed consent.

Table 1 Characteristics of patients with the latero- and torticollis subtypes of ST enrolled in the study

Patients' characteristics		Subtype of ST (number of patients)	
		Laterocollis	Torticollis
Gender	Male	20	24
	Female	6	8
Age	21–44 years	4	0
	45–59 years	21	24
	60–74 years	1	8
Duration of disease	>5 years	10	9
	2–5 years	15	21
	<2 years	1	2
Botulinum toxin therapy	Yes	10	14
	No	16	18
Initial Severity TWSTRS Score	Mild	3	2
	Moderate	14	22
	Severe	9	8

Results

Laterocollis subtype of ST

Phase 1 The number of patients with severe ST decreased from nine to four: five patients with severe ST moved to the group with moderate ST severity. The number of patients with moderate ST severity increased from 14 to 17, although 2 patients with moderate ST severity moved to the group with mild ST severity. Two patients with initial mild ST severity withdrew from the study after the first stage of surgery, the Byalskyy procedure, claiming that their status had improved (Fig. 6).

Phase 2 Eight of ten patients who underwent Treyak's procedure (third stage surgery) improved neurologically: two patients with severe ST (according to the

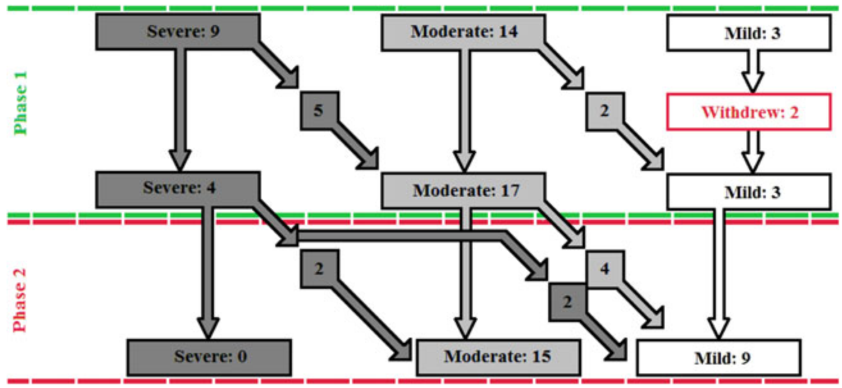

Fig. 6 Dynamics of the TWSTRS severity change in patients with the laterocollis subtype of ST

post-phase 1 data) moved to the group with moderate ST severity, and two patients moved to the group with mild ST severity; four patients with moderate ST severity moved to the group with mild ST severity. Two patients with moderate ST severity improved in the score list, although the improvement was not sufficient for them to move to the group with a lower severity level (Fig. 6).

Torticollis subtype of ST

Phase 1 The number of patients with severe ST decreased from eight to seven: one patient with severe ST moved to the group with moderate ST severity. The number of patients with moderate severity of ST decreased from 22 to 21. Two patients with initial moderate and two patients with mild ST severity withdrew from the study after the first stage surgery, the Byalskyy procedure, claiming that their status had improved (Fig. 7).

Phase 2 All 15 patients who underwent Treyak's procedure (third stage surgery) improved neurologically: 7 patients with severe ST (according to post-phase 1 data) moved to the group with mild ST severity, and 8 patients with moderate ST severity moved to the group with mild ST severity. The neurological status of two patients with moderate ST severity improved with time, although the improvement was basically due to small but sufficient changes in the severity score list (Fig. 7).

Discussion

The major advantage of staging of surgical procedures is the possibility to evaluate the effectiveness of each stage (denervation of the sternocleidomastoid muscle, first stage; denervation of the posterior cervical paravertebral muscles, second stage; Tretyak's procedure, third stage) separately and to stop whenever the surgeon and patient consider the outcome positive. Six patients (two with the laterocollis subtype of ST and four with the torticollis subtype of ST) withdrew from the study after the first stage of denervation—denervation of the sternocleidomastoid muscle—claiming that their status had greatly improved.

The phase 1 outcomes appeared to be rather satisfactory, although only a small number of patients could claim that their ST severity had significantly decreased. Only 9 patients (out of 26, 35 %) with the laterocollis

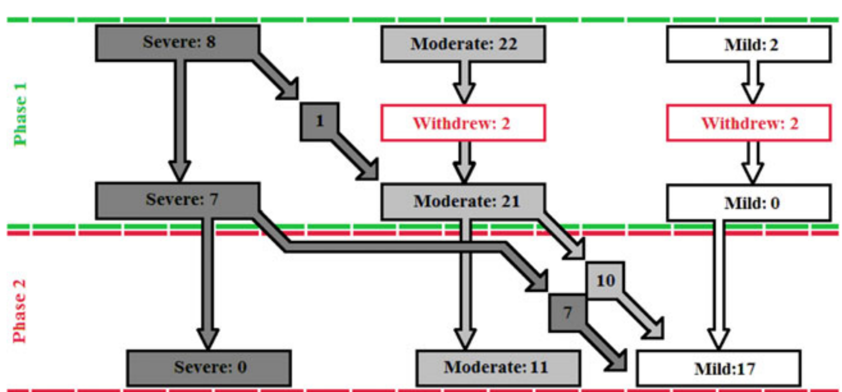

Fig. 7 Dynamics of the TWSTRS severity change in patients with the torticollis subtype of ST

subtype and 5 patients (out of 32, 16 %) with the torticollis subtype of ST claimed a decrease in ST severity according to the TWSTRS-based questionnaire (including the ones who withdrew). On the other hand, we claim that the neurological status had significantly improved in a much larger number of patients in terms of head and neck positioning. We think that the TWSTRS' accuracy is rather questionable.

The phase 2 outcomes confirmed the distinguishing efficacy of Tretyak's procedure: 92 % of patients who underwent the denervation of muscles of the omotrapezoid triangle moved to the group with lower ST severity—predominantly to the group with mild severity (21 patients out of 25). Tretyak's procedure appeared to be effective in 100 % of patients with the torticollis subtype of ST and in 80 % of the patients with the laterocollis subtype of ST.

Based on the data obtained during our study, we propose utilizing Tretyak's procedure within a complex of staged surgical procedures to improve the outcomes of treatment of patients with residual or recurrent ST after the classic Bertrand procedure.

Conclusions

(1) Staging of surgical denervation of muscles of the neck in the treatment of patients with the latero- and torticollis subtypes of ST allows the surgeon to precisely evaluate the outcomes of previously conducted procedures, individualize the surgical approach by providing the necessary time and space to create a well-defined plan and thoroughly define the aims for further surgical denervation.

(2) Tretyak's procedure appears to be an effective additional surgical application in terms of improving the outcomes of the "classic" microsurgical denervation of muscles of the neck in patients with the latero- and torticollis subtypes of ST.

Compliance with ethical standards

Funding No funding was received for this research.

Conflict of Interest All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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