Restoration of Winged Scapula in Upper Arm Type Brachial Plexus Injury: Anatomic Feasibility

Rattavuth Raksakulkiat MD*, Somsak Leechavengvongs MD**,
Kanchai Malungpaishrope MD**, Chairoj Uerpairojkit MD**,
Kiat Witoonchart MD**, Sukumal Chongthammakun PhD***

** Department of Orthopaedics, Vajira Hospital, Bangkok, Thailand*
*** Upper Extremity & Reconstructive Microsurgery Unit, Institute of Orthopaedics, Lerdsin General Hospital, Bangkok, Thailand*
**** Department of Anatomy, Mahidol University, Bangkok, Thailand*

Background: *The patients who have C_5-C_6 root avulsion in brachial plexus injury, suffered from loss of elbow flexion, shoulder abduction and winged scapula. The purpose of study is to provide anatomic feasibility of thoracodorsal nerve (medial and lateral branches) and long thoracic nerve for restoration of the shoulder function caused by winged scapula.*

Material and Method: *To study the length of thoracodorsal nerve and long thoracic nerve from the apex of the posterior axillary line to the insertion of the latissimus dorsi muscle and the serratus anterior muscle respectively, 10 fresh cadavers were dissected. The distance between the thoracodorsal nerve and long thoracic nerve, and the numbers of fascicles and axon were measured by histomorphometry. We transferred the lateral branch of the thoracodorsal nerve to the long thoracic nerve in order to restore the serratus anterior muscle function.*

Results: *The mean length of the thoracodorsal nerve from apex of posterior axillary line to bifurcation before separation to medial and lateral branches was 31.5 mm. The average length of the thoracodorsal nerve and long thoracic nerve from bifurcation to the insertion of the latissimus dorsi muscle and the serratus anterior muscle were 10.3, 82.2, and 99.5 mm, respectively. The distance between the lateral branch of the thoracodorsal nerve and long thoracic nerve was 33.4 mm. The mean number of myelinated nerve fiber of the thoracodorsal nerve medial and lateral branches and long thoracic nerve were 973.8, 1843.3 and 1135.3 axons, respectively.*

Conclusion: *The anatomic study of the thoracodorsal nerve and long thoracic nerve showed that the lateral branch of the thoracodorsal nerve is proper in the length and numbers of axon to transfer to the long thoracic nerve for restoration of shoulder function caused by the winged scapula.*

Keywords: *Brachial plexus injury, nerve transfer, Long thoracic nerve, Thoracodorsal nerve, winged scapula*

J Med Assoc Thai 2009; 92 (Suppl 6): S244-50
Full text. e-Journal: *http://www.mat.or.th/journal*

Brachial plexus injury is a common and frequent occurring clinical problem. Patients who have a sustained brachial plexus injury (C_5-C_6 root avulsion) will present with limited elbow flexion, shoulder abduction and winged scapula. Various treatments of restoring the functional affected part have been proposed, including nerve transfer, pedicle muscle transfer, free functional muscle transfer, tendon transfer and arthrodesis. This varies from patient to patient and depends on time after injury, donor nerve and experience of surgeon. However, at the present, the principal approach to treatment of brachial plexus injury is nerve transfer.

The muscles that stabilize the scapula include the trapezius, serratus anterior and levator scapulae. The scapula stabilizers also play an important role in shoulder joint movement. There are three joints in the shoulder complex including the glenohumeral (the main joint), sternoclavicular, and the acromioclavicular joints. Normal shoulder function requires smooth integration

Correspondence to: Raksakulkiat R, Department of Orthopaedics, Vajira Hospital, Bangkok 10300, Thailand.

of movement of these joints. This integrated movement of these joints during arm movement is referred to as 'scapulohumeral rhythm'. The rhythm of the gleno-humeral joint is related to scapulothoracic joints movement.

Winged scapula is defined as a medial translation of the scapula, rotation of the inferior angle toward the midline and prominence of the border of scapula which results in disrupting glenohumeral rhythm. This condition is due to a number of etiologies, however, the main causes are injury to the spinal accessory and long thoracic nerves that innervate the trapezius and serratus anterior muscles, respectively. The scapular winging from long thoracic nerve injury occurs due to the serratus anterior muscle palsy. It must be recognized that not simply an aesthetic issue. The compensatory muscular activity required to improve shoulder stability is associated with secondary pain and spasm due to muscle imbalances.

As described above, nerve transfer is the most preferred method unless the patient presents very late. Therefore, in patients with less than 8 months postinjury, we prefer nerve transfer to restore function of biceps (elbow flexion), deltoid, supraspinatus and infraspinatus (shoulder abduction and external rotation). With this procedure, transfer ulna nerve fascicles to the motor branch of the biceps muscle for elbow flexion, transfer of a nerve branch of the long head, lateral head, or medial head of the triceps muscle to the distal deltoid motor branch of the damaged axillary nerve for deltoid function and transfer of a spinal accessory nerve branch to the suprascapular nerve for dual innervation of the shoulder were performed. Nevertheless, after the operation, the patients still have winged scapula, complain of pain, weakness and limitation of shoulder abduction.

The aim of this study was to provide the anatomic feasibility of thoracodorsal nerve (medial and lateral branches) and long thoracic nerve for restoring the shoulder function from scapular winging in patients with C_5 through C_6 root avulsion.

Material and Method

The study was performed on 10 fresh cadavers. To facilitate the dissection, each cadaver was placed in the supine position with a sandbag beneath the dissected shoulder. Briefly, an incision was made from the posterior axillary line downward until mid chest level along the anterior border of latissimus dorsi muscle. The thoracodorsal neurovascular was then identified and dissected to reach the thoracodorsal nerve. After that, the thoracodorsal nerve was traced distally to the site of bifurcation to the medial and lateral branch until the insertion into latissimus dorsi muscle. Then the long thoracic nerve was dissected from axillar region until the first branch inserted into the serratus anterior muscle, corresponding to the sixth rib region. The following were measured:

1. The length of thoracodorsal nerve beginning at the apex of posterior axillary line to the bifurcation to the medial and lateral branches.

2. The length of thoracodorsal nerve from bifurcation to insertion into latissimus dorsi muscle.

3. The length of long thoracic nerve from the top of posterior axillary line to insertion into serratus anterior muscle.

4. The distance between thoracodorsal nerve (lateral branches) and long thoracic nerve at the same level of bifurcation of thoracodorsal nerve.

5. The numbers of fascicles and axons

Then, the nerves were cut then immersed immediately in a 2.5% solution of glutaraldehyde buffered with cacodylate, postfixed with 2% osmium tetroxide and embedded in epoxy resin. Semi-thin sections of 1.5 micrometer were obtained by using an ultramicrotome. The sections were stained with 1% paraphenylene-diamine in absolute alcohol and examined under light microscope. Finally, the nerves were taken for histomorphometric evaluation on the images by using analysis software (Image Pro Plus; Media Cybernetics Inc, Silver Spring).

In our clinical study, we transferred the lateral branch of the thoracodorsal nerve to the long thoracic nerve in order to restore the serratus anterior muscle function.

Results

The anatomical study of the limbs from the 10 adult human cadavers (8 males and 2 females) showed that the mean length of the thoracic nerve from the apex of the posterior axillary line to bifurcation site which separated to the medial and lateral branch was 31.5 mm (Table 1).

Table 2 shows the mean length of thoracodorsal nerve, the medial and lateral branches from the bifurcation to the insertion of latissimus dorsi and the long thoracic nerve from the apex of the posterior axillary line to the insertion of serratus anterior muscle which were 10.3, 82.2 and 99.5 mm, respectively. The distance between the lateral branch of the thoracodorsal nerve and the long thoracic nerve was 33.4 mm.

Number of fascicle of thoracodosal nerve medial and lateral branch and the long thoracic nerve was shown in the following tables.

Discussion

Winged scapula is the dyskinetic problem of shoulder which can cause discomfort, decreased shoulder strength and range of motion. Injury to the long thoracic nerve causing paralysis or weakness of the serratus anterior muscle can be disabling. Patients with serratus palsy may present with pain, weakness, limitation of shoulder elevation, and scapular winging with medial translation of the scapula, rotation of the inferior angle toward the midline, and prominence of the vertebral border. Case reports of winged scapula have been demonstrated and the treatments in restoration the shoulder function due to the serratus anterior muscle palsy have also been proposed. Although multiple surgical reconstruction have been described, the treatment by transfer of part of the pectoralis major tendon to the inferior angle of the scapula reinforced with fascia or tendon autograft is choice[5]. Many series have shown good to excellent results, with consistent improvement in function, elimination of winging, and reduction of pain[4].

Although nonoperative treatment is successful in some patients, failures have led to the evolution of surgical techniques involving various combinations of fascial graft and/or transfer of adjacent muscles. Another method of reconstruction for the serratus anterior palsy is a two-incision, split pectoralis major transfer without fascial graft. With this procedure, Gregory and coworkers reported that at a minimum follow-up of 16 months (mean, 47 months), six patients who underwent split pectoralis transfer also improved American Shoulder and Elbow Surgeons Shoulder scores (53.3-63.8), forward elevation (158.2-164.5), and visual analog scale (5.0-2.9). The authors suggested that these tendon transfers were effective for treating

Table 1. Distance of the thoracodorsal nerve from the apex of the posterior axillary line to bifurcation site before separation to the medial and lateral branch

Subject	Distance from the apex of the posterior axillary line to bifurcation site (mm)
1	25
2	32
3	28
4	30
5	32
6	40
7	35
8	29
9	31
10	36
Mean	31.5

Table 2. Length of the thoracodorsal nerve medial and lateral branch and the long thoracic nerve from apex of posterior axillary line to insertion into the latissimus dorsi muscle and the serratus anterior muscle

Subject	Thoracodorsal nerve		Long thoracic nerve	Distance between thoracodorsal nerve and long thoracic nerve (millimeters)
	Medial branch	Lateral branch		
	Length from bifurcation to latissimus dorsi (millimeters)	Length from bifurcation to latissimus dorsi (millimeters)	Length from apex of posterior axillary line to serratus anterior (millimeters)	
1	13	81	105	42
2	10	85	82	33
3	17	80	103	27
4	9	79	98	35
5	8	82	97	44
6	12	82	109	30
7	9	95	91	31
8	9	83	105	32
9	9	77	110	28
10	7	78	95	32
Mean	10.3	82.2	99.5	33.4

Table 3. Number of the fascicle of the thoracodorsal nerve medial and lateral branch and the long thoracic nerve

Thoracodorsal nerve						
Medial branch						
Number of fascicle	3	2	3	3	2	2
Number of nerve fiber (total)	984	1,006	891	783	993	1,186
Mean number of nerve fibers			973.8			
Lateral branch						
Number of fascicle	4	2	3	4	4	4
Number of nerve fiber (total)	1,745	1,747	1,210	1,520	2,385	2,453
Mean number of nerve fibers			1,843.3			

Table 4. Number of fascicle of the long thoracic nerve

Long thoracic nerve						
Number of fasicle	2	3	5	4	4	5
Number of nerve fiber (total)	1,416	1,569	1,454	1,327	509	537
Mean number of nerve fibers			1 135.3			

scapular winging in patients who did not respond to nonoperative treatment[8]. Similarly, a study of split pectoralis major tendon transfer (sternal head) in 11 patients with symptomatic scapular winging due to palsy of the serratus anterior muscle showed that at an average follow-up of 41 months, 10 of 11 (91%) patients had satisfactory results with significant improvement in function and reduction of pain. Each of these 10 patients had improved scapular tracking with no scapular winging or mild, dynamic winging[7].

In a case report, the medial pectoral nerve transfer to the long thoracic nerve was performed via an 11-cm sural nerve graft to treat scapular winging 4 months following nerve injury caused during axillary node dissection. Neurophysiological and clinical outcome 18 months postoperatively revealed successful reinnervation of the serratus anterior muscle, decreased scapular winging, and symptomatic improvement from the patient's perspective[2]. The case described in this report illustrates yet another indication for which neurotization may be a useful technique.

Novak & Mackinnon reported a 17-year-old patient with a long thoracic nerve palsy following an idiopathic onset of weakness to the serratus anterior muscle. The patient underwent a thoracodorsal nerve to long thoracic nerve transfer to reinnervate the serratus anterior muscle. Follow-up 6.5 years following the nerve transfer revealed no scapular winging, full range of motion of the shoulder and no reported functional shoulder restriction. They concluded that a thoracodorsal to long thoracic nerve transfer resulted in good functional recovery of the serratus anterior muscle[3].

A descriptive study of the anatomical characteristics of the upper serratus anterior has demonstrated wide variation in upper serratus anterior anatomy and noted to be distinct in appearance and peripheral innervation from the middle and lower serratus anterior[1]. Another anatomic study of the long thoracic nerve in relation to the anatomic landmarks and reference lines, the axillary lines and the first 2 ribs has also been published[6]. The serratus anterior muscle consisted of the upper, middle, and lower parts. The upper part is supplied mainly by the C_5 nerve root, and the C_4, C_6, or C_7 nerve roots has also multiple branches in most dissections (64 of 70). The long thoracic nerve, consisting of the C_6 and C_7 nerve roots, innervated the middle and lower parts. The upper part traversed in a posterior direction compared with the middle or lower part. The upper part of the muscle, which is supplied from multiple nerve roots and runs in a posterior direction, may stabilize the rotational motion of the scapula on the thorax in shoulder elevation. The middle part provides the scapular abduction, and the lower part contributes to upward rotation, abduction, and posterior tilting[9].

Different derivations of the long thoracic nerve have been observed, and C_{4-7}, C_{5-7}, C_5 and C_7, C_{5-7}, C_{5-8}, C_6 and C_7 and branch from C_6 have been the most important components of the long thoracic nerve[10]. The limitations of this anatomic feasibility study of the serratus anterior muscle, long thoracic nerve and thoracodorsal nerve are the reconstruction of small to moderate-sized defects, origin arising from cervical nerve root, free functional muscle transferring for face and hand reanimation. The serratus anterior muscle has this potential because two or more individual muscle slips can be transferred on a single vascular pedicle. Serratus anterior muscle slips 5 through 9 in cadavers were studied following intraarterial latex injection with a radiopaque material (latex/diatrizoate/lead mixture) for x-ray delineation of the intramuscular vascular pattern. Slips 5 through 9 were consistently supplied by a single dominant branch of the thoracodorsal artery and innervated by the long thoracic nerve. There was a consistent vascular pattern to each muscle slip, in which the serratus artery gives rise to common slip arteries, each of which supplies adjacent muscle slips. These findings imply that the slips may be separated to the level of these common slip arteries, with up to five slips transferred on a single neurovascular pedicle and each slip oriented independently to provide multiple muscle force vectors. With these possibilities, the reconstructive surgeon may be able to restore more natural facial animation and better intrinsic muscle function in the upper extremity[11].

The ideal donor muscle for facial reanimation has to be found. Donor muscles commonly used, such as the gracilis and pectoralis minor, are limited. Face reanimation muscles such as the orbicularis oculi and orbicularis oris could possibly be reconstructed in their proper anatomical positions with the serratus anterior muscle. [13]

Conclusion

We study the anatomic feasibility of the thoracodorsal nerve and long thoracic nerve in order to find out proper nerve transfer to restore of the serratus anterior muscle function. Our study showed the average length of the thoracodorsal nerve, medial and lateral branches, and long thoracic nerve from bifurcation to the insertion of the latissimus dorsi muscle and the serratus anterior muscle of 10.3, 82.2, and 99.5 mm, respectively. The distance between the lateral branch of the thoracodorsal nerve and long thoracic nerve of 33.4 mm showed that the length of the lateral branch of the thoracodorsal nerve was suitable to transfer to the long thoracic nerve for correction winged scapula. Clinical trial in patient who has C_5-C_6 root avulsion injury and winged scapula has been published which showed good to excellence results for trying reconstruction of shoulder motion without any deficiency of donor nerve[14].

References

1. Smith R Jr, Nyquist-Battie C, Clark M, Rains J. Anatomical characteristics of the upper serratus anterior: cadaver dissection. J Orthop Sports Phys Ther 2003; 33: 449-54.
2. Tomaino MM. Neurophysiologic and clinical outcome following medial pectoral to long thoracic nerve transfer for scapular winging: a case report. Microsurgery 2002; 22: 254-7.
3. Novak CB, Mackinnon SE. Surgical treatment of a long thoracic nerve palsy. Ann Thorac Surg 2002; 73: 1643-5.
4. Wiater JM, Flatow EL. Long thoracic nerve injury. Clin Orthop Relat Res 1999; 17-27.
5. Perlmutter GS, Leffert RD. Results of transfer of the pectoralis major tendon to treat paralysis of the serratus anterior muscle. J Bone Joint Surg Am 1999; 81: 377-84.
6. Ebraheim NA, Lu J, Porshinsky B, Heck BE, Yeasting RA. Vulnerability of long thoracic nerve: an anatomic study. J Shoulder Elbow Surg 1998; 7: 458-61.
7. Connor PM, Yamaguchi K, Manifold SG, Pollock RG, Flatow EL, Bigliani LU. Split pectoralis major transfer for serratus anterior palsy. Clin Orthop Relat Res 1997; 134-42.
8. Galano GJ, Bigliani LU, Ahmad CS, Levine WN. Surgical treatment of winged scapula. Clin Orthop Relat Res 2008; 466: 652-60.
9. Hamada J, Igarashi E, Akita K, Mochizuki T. A cadaveric study of the serratus anterior muscle and the long thoracic nerve. J Shoulder Elbow Surg 2008; 17: 790-4.
10. Wang JF, Dang RS, Wang D, Zhang ZY, Liu Z, Huang HL, et al. Observation and measurements of long thoracic nerve: a cadaver study and clinical consideration. Surg Radiol Anat 2008; 30: 569-73.
11. Godat DM, Sanger JR, Lifchez SD, Recinos RF, Yan JG, Godat MR, et al. Detailed neurovascular anatomy of the serratus anterior muscle: implications for a functional muscle flap with multiple

independent force vectors. Plast Reconstr Surg 2004; 114: 21-9.
12. Tubbs RS, Salter EG, Custis JW, Wellons JC III, Blount JP, Oakes WJ. Surgical anatomy of the cervical and infraclavicular parts of the long thoracic nerve. J Neurosurg 2006; 104: 792-5.
13. Lifchez SD, Sanger JR, Godat DM, Recinos RF, LoGiudice JA, Yan JG. The serratus anterior subslip: anatomy and implications for facial and hand reanimation. Plast Reconstr Surg 2004; 114: 1068-76.
14. Uerpairojkit C, Leechavengvongs S, Witoonchart K, Malungpaishorpe K, Raksakulkiat R. Nerve transfer to serratus anterior muscle using the thoracodorsal nerve for winged scapula in C5 and C6 brachial plexus root avulsions. J Hand Surg Am 2009; 34: 74-8.
15. Kurokawa M, Yamada N, Suzuki S, Muneuchi G. Long-term follow-up of reconstruction of four metatarsal bone and soft-tissue defects using a serratus anterior muscle rib osteomyocutaneous free flap. Plast Reconstr Surg 2004; 114: 1553-5.

การฟื้นฟูการยกตัวขึ้นของกระดูกสะบักในกรณีที่เกิดอัมพาตของแขนท่อนบนจากการบาดเจ็บที่ร่างแหเส้นประสาทที่ควบคุมแขน: การศึกษาลักษณะทางกายวิภาค

รัฐวุฒิ รักษากุลเกียรติ, สมศักดิ์ ลีเชวงวงศ์, ขรรค์ชัย มลังไพศรพณ์, ชัยโรจน์ เอื้อไพโรจน์กิจ, เกียรติ วิฑูรชาติ, สุขุมาล จงธรรมคุณ

ภูมิหลัง: *ผู้ป่วยที่ได้รับอุบัติเหตุที่รากประสาทคอเส้นที่ 5 – 6 แบบกระชากขาด มักมีภาวะทุพพลภาพจากการสูญเสียความสามารถในการกางไหล่ งอข้อศอก และทำให้กระดูกสะบักกางออก*

วัตถุประสงค์: *เพื่อหาลักษณะทางกายวิภาคของเส้นประสาท thoracodorsal และ เส้นประสาท long thoracic ตลอดจนความยาวของเส้นประสาทและจำนวน axon ของเส้นประสาท เพื่อการแก้ไขภาวะการกางออกของกระดูกสะบัก*

วัสดุและวิธีการ: *ทำการศึกษาโดยการผ่าตัดในผู้เสียชีวิตไม่นานเกิน 12 ชั่วโมง จำนวน 10 ราย เพื่อศึกษาความยาวของเส้นประสาท thoracodorsal (แขนงทางด้านในและแขนงทางด้านนอก) เส้นประสาท long thoracic จากเส้นสมมติบริเวณด้านหลังรักแร้จนถึงจุดเกาะเข้าของกล้ามเนื้อ latissimus dorsi และกล้ามเนื้อ serratus anterior ตามลำดับ ระยะห่างระหว่างเส้นประสาท thoracodorsal และเส้นประสาท long thoracic จำนวน fascicle และ axon ของเส้นประสาท thoracodorsal และเส้นประสาท long thoracic โดยวิธีทางจุลพยาธิวิทยา โดยศึกษาการย้ายแขนงทางด้านนอกของเส้นประสาท thoracodorsal ไปเชื่อมต่อกับเส้นประสาท long thoracic*

ผลการศึกษา: *ความยาวเฉลี่ยของเส้นประสาท thoracodorsal จากเส้นสมมุติทางด้านหลังของรักแร้จนถึงจุดก่อนการแตกแขนงเป็นแขนงทางด้านในและด้านนอก คือ 31.5 มิลลิเมตร ความยาวเฉลี่ยของเส้นประสาท thoracodorsal จากตำแหน่งที่แตกแขนงเป็นแขนงทางด้านในและด้านนอกจนถึงจุดเกาะเข้ากล้ามเนื้อ latissimus dorsi คือ 10.3 และ 82.2 มิลลิเมตร ตามลำดับความยาวเฉลี่ยของเส้นประสาทlong thoracic จากเส้นสมมุติทางด้านหลังรักแร้จนถึงจุดเกาะเข้ากล้ามเนื้อ serratus anterior คือ 99.5 มิลลิเมตร ระยะห่างระหว่างแขนงทางด้านนอกของเส้นประสาท thoracodorsal และเส้นประสาทlong thoracic เป็น 33.4 มิลลิเมตร และค่าเฉลี่ยของจำนวน axon ของเส้นประสาท thoracodorsal แขนงทางด้านใน แขนงทางด้านนอก และเส้นประสาท long thoracic คือ 973.9, 1843.1 และ 1135.3 ตามลำดับ*

สรุป: *การศึกษาทางกายวิภาคความยาวและลักษณะทางจุลพยาธิวิทยาของเส้นประสาท thoracodorsal แขนงทางด้านในและแขนงทางด้านนอก และเส้นประสาท long thoracic แสดงให้เห็นว่าแขนงทางด้านนอกของเส้นประสาท thoracodorsal มีความยาวและจำนวน axon ที่เหมาะสมในการเคลื่อนย้ายไปเชื่อมต่อกับเส้นประสาท long thoracic ในการแก้ไขภาวะกระดูกสะบักกางออกในผู้ป่วยที่มีปัญหาแผงเส้นประสาทคอรากประสาทคอเส้นที่ 5-6 กระชากขาด*