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Shrug radiographs for the diagnosis of long thoracic nerve palsy in traumatic brachial plexus injury

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Background: Preoperative diagnosis of long thoracic nerve (LTN) palsy is important for shoulder reconstruction after a traumatic brachial plexus injury (BPI). In the present study, we developed an objective diagnostic method for LTN palsy for patients with traumatic BPI.
Methods: This is a retrospective review of 56 patients with traumatic BPI who had been receiving treatment at a single institution for over 8 years. The patients were divided into 2 groups: an LTN palsy group (n = 30) and a no palsy control group (n = 26). The LTN palsy group had 21 different palsy types with 4 and 5 C5-7 and C5-8, whereas the no palsy group had 18 different palsy types with 5 and 3 C5-6 and C5-8, respectively. Preoperative plain anteroposterior radiographs were taken in shoulder adduction and shrug positions. Scapulothoracic (ST) upward rotation and clavicle lateral (CL) rotation angles were measured on X-rays. The differences between the adduction and shrug positions for the respective angles were calculated and defined as Φ_{ST} and Φ_{CL}, respectively. The differences in the Φ_{ST} and Φ_{CL} values due to the presence or absence of LTN palsy were examined, the cutoff values of Φ_{ST} and Φ_{CL} for the diagnosis of LTN palsy were determined, and further sensitivity and specificity were calculated.
Results: Both Φ_{ST} and Φ_{CL} were significantly decreased in the LTN palsy group compared with the no palsy control group. The sensitivity and specificity for LTN palsy were 0.833 and 1.000 for Φ_{ST} and 0.833 and 0.840 for Φ_{CL}, respectively, when the cutoff value was set as $\Phi_{ST} = 15°$ and $\Phi_{CL} \leq 24°$.
Conclusion: Dynamic shrug radiographs provide a useful objective diagnosis of LTN palsy after traumatic BPI.
Level of evidence: Level IV; Case Control Design; Diagnostic Study

Keywords: Brachial plexus injury; long thoracic nerve; radiograph; shrug; serratus anterior muscle; trapezius muscle

Injuries to the upper and total brachial plexus (BPIs) are accompanied by severe shoulder disabilities. Traditional reconstructive procedures for acute presentations have employed nerve transfer or grafting in targeting the glenohumeral joint motion. Long thoracic nerve (LTN) repair for scapulothoracic (ST) joint abduction has been neglected in patients with C5 and C6 injuries, with a partially working serratus anterior muscle, exhibiting better surgical outcomes compared with those with C5, C6, and C7 injuries, with a completely paralyzed serratus anterior muscle, one of the agonist muscles for ST.[23] Such a contradiction stems from the difficulty in definitely diagnosing LTN palsy after BPI.

Generally, in order to diagnose LTN palsy, the patient pushes forward against the wall and the examiner needs to find any scapular winging. This examination position is

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usually impossible in patients with upper and total BPI. In addition, the presence of scapular winging is not specific to serratus anterior muscle dysfunction because it could also be caused by spinal accessory or dorsal scapular nerve palsy.[5] In 2005, Bertelli et al[1] reported on a shoulder protraction test as a diagnostic tool for LTN palsy. We think that although this is a very useful method, it is sometimes difficult to judge because of the compensation for the pectoralis minor or major muscles, or the upper body twists.

The upper trapezius, lower trapezius, and serratus anterior muscles are considered to provide an upward rotatory force couple to produce scapular rotation during the early phase of shoulder elevation.[11,18,19] Recently, Roren et al[20] demonstrated that scapular lateral rotation is reduced during arm abduction in patients with isolated LTN palsy. These data suggest that the serratus anterior muscle stabilizes the scapula and provides the upward and lateral rotation of the inferior angle of the scapula.[1,6,7] Although it is generally known that a shrug (scapular elevation) is produced by the upper portion of the trapezius, levator scapulae, and rhomboid muscles, electromyography (EMG) analyses have demonstrated that shrugs synchronously activate both the upper trapezius and the serratus anterior muscles.[4,8,18] According to these data, serratus anterior muscle dysfunction could be detected by a detailed assessment of the shrug motion in patients with upper and total BPI who cannot elevate their shoulders.

In this study, we sought to develop an objective diagnostic method for LTN palsy in patients with traumatic BPI. We measured the ST upward rotation and clavicle lateral (CL) elevation using dynamic shrug X-rays and examined their relationship with LTN palsy.

Materials and methods

Patients

This is a post hoc analysis of a retrospective case-control study. For the present study, we searched using the keyword "brachial plexus injury" in a database of our hospital's medical records between January 2011 and December 2018 and identified 309 patients. We reviewed all the medical records and extracted 83 cases of patients with traumatic BPI for whom preoperative dynamic shrug X-rays were recorded (Fig. 1). We excluded 27 patients: 14 had trapezius muscle weakness (<grade 4 in the manual muscle test), 6 had injuries at the infraclavicular level, 1 had severe shoulder contracture, 1 had untreated clavicle fracture, and 5 had an indeterminable LTN palsy status. Finally, 56 patients with traumatic BPI (53 males, 3 females; average age: 30.8 years; range: 12-80 years) were included in the present study. The patients were divided into 2 groups: LTN palsy (n = 30) and no palsy (n = 26). The affected sides in the LTN group comprised 13 right and 17 left sides, whereas in the no palsy group, it involved 15 right and 11 left sides. The LTN palsy group presented 4 C5-7, 5 C5-8, and 21 total palsies, whereas the no palsy group had 5 C5-6, 3 C5-8, and 18 total palsies. Perishoulder fracture and/or dislocation (clavicle fracture, rib fracture, scapular fracture, humeral fracture, shoulder dislocation, etc.) were concomitant with 18 and 15 patients in the LTN palsy and no palsy groups, respectively. LTN palsy was confirmed by the medical record of surgical exploration in 22 patients and by all clinical findings in all, including the remaining 8 patients. This was defined as when the serratus anterior muscle contraction was not observed after electrical stimulation at surgical exploration or when all 3 clinical assessments, that is, EMG of the infraspinatus, deltoid, and biceps muscles; magnetic resonance imaging findings of C5-7 roots; and shoulder protraction test, indicated avulsion of C5-7 roots (Table I). Contrariwise, a functional LTN was confirmed

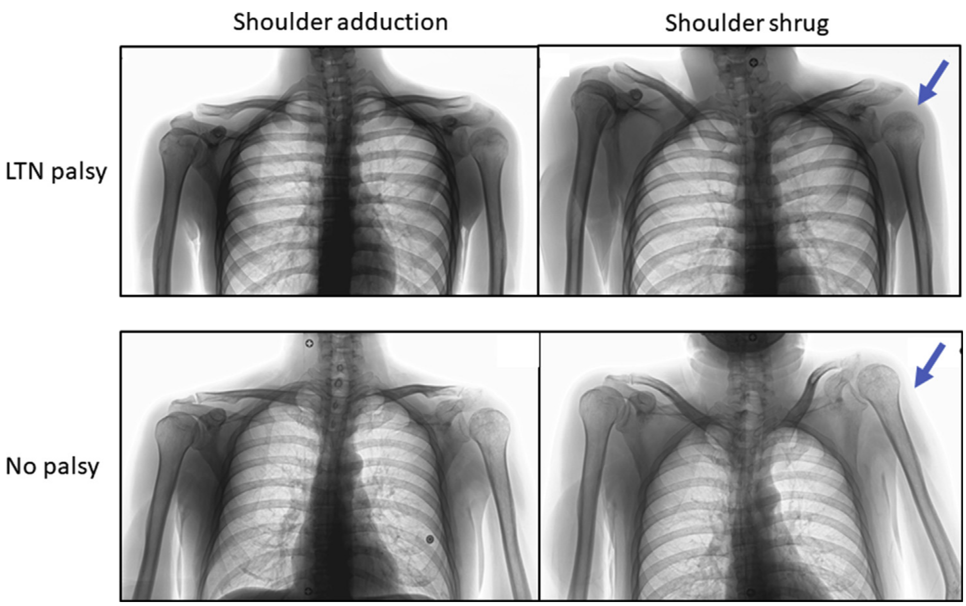

Figure 1 Representative X-rays of shoulder adduction (*left*) and shrug (*right*) in patients with LTN palsy (*upper*) and no palsy (*lower*). In both cases, the left arms are the affected side (*arrows*). *LTN*, long thoracic nerve.

Table I Criteria for long thoracic nerve palsy

		LTN palsy (+)	n	LTN palsy (−)	N
Requirement 1	Electric stimulation to LTN under surgical exploration	No contraction	22	Strong contraction	11
	OR				
Requirement 2	MRI findings of C5, 6, 7 roots	No visible rootlets	8	Normal root appearance	15
	AND				
	EMG of IS, deltoid, and biceps muscles	Denervation potential		Interferenced MUP	
	AND				
	Shoulder protraction test	≤ 3 QFB		≥4 QFB	
			30		26

LTN, long thoracic nerve; *MRI*, magnetic resonance imaging; *EMG*, electromyography, *IS*, infraspinatus; *QFB*, querfingerbreite; *MUP*, motor unit potential.

by surgical exploration and clinical findings in 11 and 15 patients, respectively.

Preoperative plain anteroposterior radiographs of both shoulder joints in the frontal plane were taken at the adduction position and subsequently in the maximal active shrug position (Fig. 1). The patients were examined in a standing position under the supervision of a hand therapist to ensure that the maximal shrug of the shoulder was reached. This retrospective study was approved by the ethical committee of our hospital.

Measurements

All measurements were performed using the Synapse PACS software (Fujifilm, Tokyo, Japan). The measurement precision was set at 1°. Magnification, contrast, and enhancement with monochrome inversion were used for better visualization of bones on radiograms. ST and CL angles were measured (Fig. 2).[22] ST is the angle between the glenoid articular surface and the vertical lines, whereas CL is the angle between the line from the midpoint of the medial end to the midpoint of the lateral end of the clavicle and the horizontal line. The difference between neutral and adduction positions and that between neutral and shrug positions were calculated and defined as Φ_{ST} and Φ_{CL}, respectively. The differences in Φ_{ST} and Φ_{CL} due to the presence or absence of LTN palsy were examined, and the cutoff values for Φ_{ST} and Φ_{CL} were determined; further sensitivity and specificity were calculated.

Data analysis

The test-retest reliability was examined using the first 20 patients. Each patient was examined twice in ≥2-hour intervals by 2 observers. Each observer measured the 2 parameters in both adduction and shrug radiographs. Interobserver and intraobserver reliabilities were assessed by the Bland-Altman analysis. Absolute reliability was assessed by the standard error of measurement and minimal detectable change (MDC). Differences between the palsy and no palsy groups on Φ_{ST} and Φ_{CL} were evaluated using Student's *t*-test. The cutoff points for Φ_{ST} and Φ_{CL} of LTN palsy were analyzed using the receiver operating characteristic curve method. These parameters were set as the diagnostic criteria of LTN palsy. The sensitivity, specificity, and accuracy were calculated from these cutoffs. Data were analyzed using commercially available software (XLSTAT; Addinsoft, Inc., New York, NY, USA). A *P* value of <.05 indicated statistical significance. All data were presented as means with ranges. Effect sizes (*d*) between 0.20 and 0.49 were considered as small, between 0.50 and 0.79 as

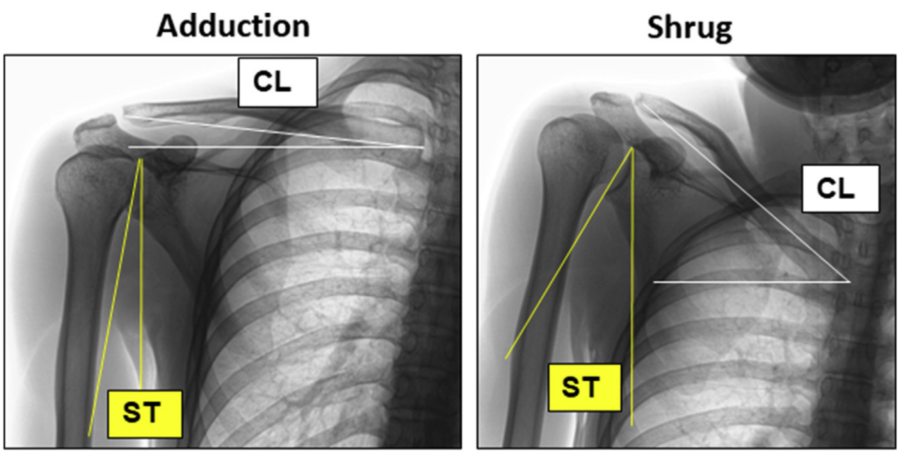

Figure 2 X-rays of an AP view of shoulder adduction and shrug in a patient with left BPI. Φ_{ST} = shrug ST − adduction ST; Φ_{CL} = shrug CL − adduction CL. *AP*, anteroposterior; *BPI*, brachial plexus injury; *ST*; scapulothoracic; *CL*, clavicle lateral.

Table II Comparison of Φ_{ST} and Φ_{CL} between the LTN palsy and no LTN palsy groups on the injury side

	LTN palsy	No palsy	Effect size (*d*)	*P* value	95% CI	Power of test
Φ_{ST}	11.2 ± 4.9°	24.6 ± 7.2°	2.21	<.0001	10.14-16.68	1
Φ_{CL}	20.6 ± 5.3°	28.6 ± 5.7°	2.11	<.0001	4.98-10.91	1

LTN, long thoracic nerve; *CI*, confidence interval.

Table III Comparison of Φ_{ST} and Φ_{CL} between the injury and contralateral healthy sides

	Injured	Contralateral	Effect size (*d*)	*P* value	95% CI	Power of test
Φ_{ST}						
LTN palsy	11.2 ± 4.9°	18.9 ± 7.7°	1.2	<.0001	4.41-11.12	1
No palsy	24.6 ± 7.2°	23.0 ± 5.0°	0.26	.363	−1.87 to 5.024	0.255
Φ_{CL}						
LTN palsy	20.6 ± 5.3°	30.2 ± 6.7°	1.59	<.0001	6.49-12.71	1
No palsy	28.6 ± 5.7°	32.4 ± 7.0°	0.6	.035	0.28-7.42	0.861

LTN, long thoracic nerve; *CI*, confidence interval.

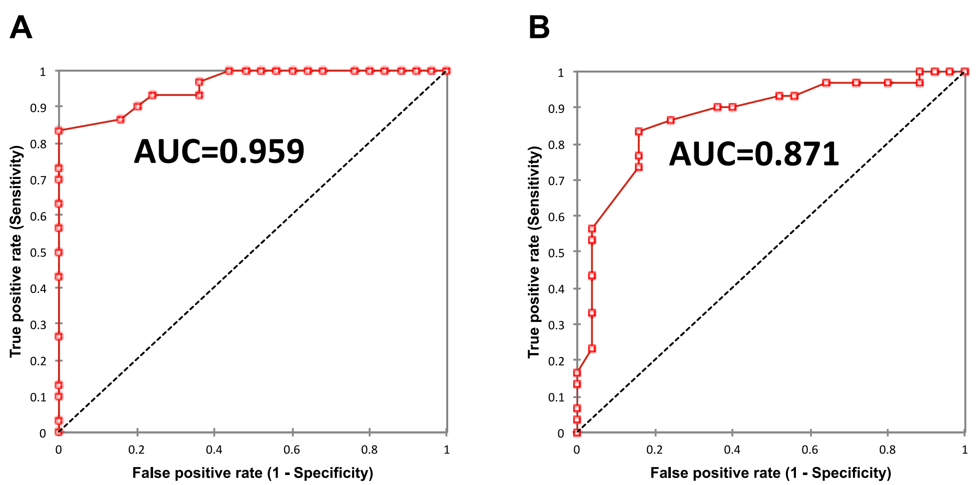

Figure 3 (**A**) ROC curve for Φ_{ST}. (**B**) ROC curve for Φ_{CL}. *ROC*, receiver operating characteristic; *AUC*, area under the curve.

moderate, and ≥0.80 as large. A power of <0.8 indicated the possibility of type II error (inadequate sample size).

Results

The Φ_{ST} and Φ_{CL} values of the injured side in the no LTN palsy group were 24.6° and 28.6°, respectively, whereas they were significantly reduced to 11.2° ($P < .0001$, $d = 2.21$) and 20.6° ($P < .0001$, $d = 2.11$) in patients with LTN palsy (Table II). When compared with the contralateral healthy side, Φ_{ST} was also significantly lower in the LTN palsy group ($P < .0001$) (Table III), whereas Φ_{ST} between the injured and contralateral healthy sides in patients with no LTN palsy exhibited no statistically significant difference ($P = .363$, power = 0.255). Similarly, Φ_{CL} was significantly decreased in the injured side compared with the contralateral healthy side ($P < .0001$, $d = 1.59$) for the LTN palsy group. However, Φ_{CL} of the injured side in patients with no LTN palsy was significantly decreased compared with that of the contralateral healthy side ($P = .035$, $d = 0.6$).

Using the ROC curve analysis, we could determine the cutoffs of Φ_{ST} and Φ_{CL} that would provide the highest sensitivity and specificity for diagnosing LTN dysfunction. The sensitivity and specificity for the diagnosis of LTN palsy were 0.833 and 1.000 in Φ_{ST} and 0.833 and 0.840 in Φ_{CL}, respectively, when the cutoff value was set to 15° for Φ_{ST} and ≤24° for Φ_{CL} with an area under the curve of 0.959 and 0.871, respectively (Fig. 3, Table IV).

Table IV Diagnostic test for LTN palsy cutoff

	Degrees	Sensitivity	Specificity	Accuracy
Φ_{ST}	15	0.833	1	0.909
Φ_{CL}	24	0.833	0.840	0.836

LTN, long thoracic nerve.

The MDC results by the Bland-Altman analysis for 2 parameters are listed in Table V. The MDCs ranged from 2° (Φ_{CL} on rater 1) to 5° (Φ_{ST} on inter-rater); these values were used for the maximal error measurement.

Discussion

In this study, we demonstrated a quantitative diagnosis of traumatic BPI-associated LTN palsy using the Φ_{ST} or Φ_{CL} cutoffs in dynamic shrug X-rays. Besides, both Φ_{ST} and Φ_{CL} were significantly reduced on the injured side compared with the contralateral healthy side for patients with LTN palsy. This result suggests that LTN palsy can be predicted to some extent by comparison with the healthy side of patients with LPS palsy. However, compared with Φ_{ST}, Φ_{CL} was inferior in terms of sensitivity and specificity in diagnosing LTN palsy, and further Φ_{CL} on the injury side of patients without LTN palsy was markedly decreased compared with the healthy side. The lower diagnostic rate of LTN palsy by Φ_{CL} could be because the serratus anterior muscle is not directly attached to the clavicle, or the clavicle is pulled downward by the weight of the paralyzed upper extremity. Therefore, Φ_{ST} is better suited for the diagnosis of traumatic BPI-associated LTN palsy than Φ_{CL}.

Thus far, it has been clear that both the serratus anterior and the trapezius muscles function during shrug exercise, but there have been no reports on the extent of each muscle's involvement in scapular upward rotation.[4,8,18] Our 2-dimensional (2D) measurement on the X-rays demonstrated that the scapula rotated upward at approximately 24.6° at a shrug, and it was suggested that about half of this, 13.4°, was due to the action of the serratus anterior muscle. Scapular motion during shoulder elevation has been studied by various methods. In 1944, Inman et al[9] demonstrated a 2D analysis of radiographs to describe the scapular position. Recently, several researchers have advanced to 3-dimensional (3D) analyses of scapular kinematics using 3D radiographic digitization and electromagnetic-based systems as the scapular movement is not planar.[2,12-14] According to these data, it seems that scapular upward rotation occurs at approximately 50° at the maximum shoulder elevation. A shoulder elevation involves more than twice as many scapular upward rotations compared with a shrug. Although the reasons remain unclear, it has been suggested that the joint capsule, rotator cuff, teres major, long head of the triceps, and latissimus dorsi positively work for additional scapular upward rotation during elevation; or downward scapular rotators, such as levator scapulae and rhomboid muscles, are more involved in a shoulder shrug.[17] Our study also demonstrated that the clavicle is abducted at approximately 30° during a shrug, whereas it has been reported that the clavicle is abducted at approximately 10° during shoulder elevation.[13,15,16] The predominant functioning of the upper fibers of the trapezius muscle during a shrug, as compared to a shoulder elevation, could explain this. Thus, the difference between the scapular motion of a shoulder shrug and that of elevation and the extent to which scapular upward rotation is possible with the serratus anterior muscle alone remains unknown.

The serratus anterior muscle has 3 major divisions (upper, intermediate, and lower) according to the muscle fiber origin, direction, and insertion. Among these, the lower portion originates from the third to the eighth or tenth rib and could mostly affect the scapular upward rotation, together with the trapezius, during arm abduction.[7,10] In addition, Bertelli et al[1] indicated that the lower part is the most important for scapular stabilization. However, these functions are speculated on the basis of anatomic and surgical findings. Further biomechanical studies are required to clarify the exact function of the different portions of the serratus anterior muscle.

The common clinical finding of LTN palsy is the presence of scapular winging, which is revealed by shoulder forward flexion or by pushing against a wall with the arms

Table V Bland-Altman analysis for Φ_{ST} and Φ_{CL}

Test	Pair	Rater 1	Rater 2	Effect size (*d*)	SEM	95% CI	Bias	MDC95
Interrater	Φ_{ST}	16.8 ± 10.8	16.8 ± 10.1	−0.25	2.552	−.444 to 0.944	−0.25	5.00209
	Φ_{CL}	23.4 ± 7.6	23.0 ± 7.7	−0.4	1.142	−0.935 to 0.135	−0.4	2.23926
Intrarater								
Rater 1	Φ_{ST}	16.9 ± 10.1	16.8 ± 10.8	−0.15	2.39	−1.269 to 0.969	−0.15	4.68483
	Φ_{CL}	23 ± 7.5	23.4 ± 7.6	0.4	1.046	−0.090 to 0.890	0.4	2.05074
Rater 2	Φ_{ST}	15.9 ± 10.2	16.8 ± 10.1	0.9	2.447	−0.245 to 2.045	0.9	4.79679
	Φ_{CL}	23.1 ± 7.6	23.0 ± 7.7	−0.15	1.461	0.834 to 0.534	−0.15	2.863

SEM, standard error of the mean; *CI*, confidence interval; *MDC95*, minimal detectable change at the 95% CI.

stretched out in front horizontally, or at push-ups.[7] Unfortunately, almost all patients with traumatic BPI cannot perform such a shoulder motion. Alternatively, EMG,[11,21,24] MRI[3], and shoulder protraction test 1 are also valuable adjuncts for diagnosing LTN palsy. The shrug X-ray test is a new more accurate diagnostic tool in addition to those methods, although there is a risk of X-ray exposure.

Our study has several limitations. The main limitations of this study include its retrospective nature, the small sample size, patient selection bias, and the various injuries due to repeated X-ray intervals between our comparison groups. Second, the study involved heterogeneous data regarding the type of palsy. Third, scapular motion is 3D, not 2D (planar), and dominance of the hand/upper limb was ignored.[14] Finally, not all cases were confirmed by direct surgical exploration for the presence or absence of LTN palsy.

Conclusion

The shrug test on X-rays is a useful method for diagnosing LTN palsy in patients with traumatic upper and total BPI. This test, in combination with previously reported methods, can improve the diagnostic efficiency of LTN palsy, as well as the outcomes of LTN repair and postoperative shoulder function.

Disclaimer

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