Isolated paralysis of the serratus anterior muscle: Surgical release of the distal segment of the long thoracic nerve in 52 patients

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ABSTRACT

Introduction: Isolated serratus anterior (SA) paralysis is a rare condition that is secondary to direct trauma or overuse. Patients complain of neuropathic pain and/or muscle pain secondary to overexertion of the other shoulder stabilizing muscles. As the long thoracic nerve (LTN) passes along the thorax, it can be compressed by blood vessels and/or fibrotic tissue. The goal of the current study was to evaluate the outcomes of surgical release of the distal segment of the LTN in cases of isolated SA paralysis.

Patients and methods: This was a retrospective study of 52 consecutive cases operated on between 1997 and 2012. The average patient age was 32 years (range 13–70). Patients had been suffering from paralysis for an average of 2 years (range 4–259 months); the paralysis was complete in 52% of cases. Every patient underwent a preoperative electroneuromyography (ENMG) assessment to confirm that only the SA was affected and there were no signs of re-innervation.

Results: Every patient had abnormal intraoperative findings. There were no complications. All patients showed at least partial improvement following the procedure. The improvement was excellent or good in 45 cases (86.7%), moderate in 4 cases (7.7%) and slight in 3 cases (5.6%). In 32 cases (61.5%), the winged scapula was completely corrected; it was less prominent in 19 cases and was unchanged in one case. The best outcomes following surgical release occurred in patients who presented without preoperative or neuropathic pain and were treated within 18 months of paralysis.

Discussion: Isolated SA paralysis due to mechanical injury resembles entrapment neuropathy. We discovered signs of LTN compression or restriction during surgery. Surgical release of the distal segment of the LTN is a simple, effective treatment for pain that provides complete motor recovery when performed within the first 12 months of the paralysis.

Level of evidence: IV.

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1. Introduction

The serratus anterior (SA) muscle is innervated by the long thoracic nerve (LTN), which arises from collateral branches of the C5, C6 and C7 nerve roots. After C5 and C6 have joined together, the transverse trunk crosses the middle scalene muscle before being joined by the C7 branch. It goes around the second rib and then descends along the lateral thoracic wall under the SA muscle fascia [1] (Fig. 1). At the proximal edge of the distal SA head, it is joined by a collateral branch of the thoracodorsal artery (serratus anterior branch), which crosses over the LTN before dividing into terminal muscle branches. The nerve can be easily identified at this cross-over point [2].

The main action of the SA is to stabilize the scapula against the thoracic wall. If paralysed, the scapula wings out, especially during forward elevation of the arm. Other scapula-stabilizing muscles (especially the trapezius, rhomboids and levator scapulae) can only partially compensate for this deficit, and can become painful, even go into spasm. If the deficit persists, anterior impingement gradually closes the subacromial space because of the scapular tipping [3,4].

Serratus anterior paralysis was first reported with Parsonage-Turner syndrome (PTS), also known as brachial neuritis [5], a rare condition of unknown aetiology that affects 1.64 out of every 100,000 individuals [6]. PTS is the result of inflammation in the brachial plexus [7]. In a fair number of cases, electroneuromyography (ENMG) studies have found that other muscles are also

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partially affected. In this context, the motor deficit is preceded by a few weeks of acute pain, which disappears once paralysis settles in. Typically, the deficit spontaneously resolves itself within a few months [8,9].

Isolated paralysis of the LTN can occur after chest or axillary surgery due to direct nerve injury [10]. In such cases, early repair of the nerve provides the best chance of recovery. LTN injury can also occur after closed direct trauma or when the shoulder and arm are used repeatedly [10,11]. In cases of mechanically-induced paralysis, partial or no spontaneous recovery of activity can be expected [12,13].

Proximal compression, as the nerve passes through the middle scalene muscle [1,14] or goes over the second rib [15], is the most commonly proposed injury mechanism. We have also shown that the LTN can be restricted by the SA fascia or direct vascular branches of the lateral thoracic artery crossing over the nerve [16]. The possibility of distal compression has also been brought up by Manning et al. [17]. In a non-PTS context, non-iatrogenic serratus anterior paralysis has been treated by surgical release of the distal segment of the LTN. The goal of the current study was to evaluate the outcomes of this treatment in our first 52 cases.

2. Patients and methods

From 1997 to 2012, 66 patients were seen in our department for isolated SA paralysis. There were 44 men and 22 women, with an average age of 32 years (range 13–70) at the time of diagnosis. The initial clinical examination was used to determine the patient’s dominant arm, injured side, duration of the paralysis, degree of paralysis, mechanism of injury, presence and location of any pain and presence of Tinel’s sign over the LTN trajectory. The paralysis was labelled as either complete (entire axial edge of the scapula lifted in neutral position, visible during forward elevation of the arm, without possibility of recruitment when pushing against a wall) or partial (incomplete lifting of the scapula, especially at the tip, mainly visible during forward elevation of the arm, but relieved by pushing against a wall). It seemed to us that there was no way to more precisely defining the deficit. An ENMG study was performed initially and during the postoperative follow-up.

The following criteria were used for a surgical indication: partial or complete isolated, non-iatrogenic SA paralysis following a single closed direct trauma or repetitive use during sports or work-related activities, or an abnormal posture, which was present for at least 3 months, with no clinical or ENMG signs of recovery.

Of the 66 eligible patients, 14 were excluded: four paralysis cases were secondary to thoracic surgery; four refused the surgical procedure; one patient presented with chronic complete paralysis, with no pain but complete SA atrophy; one patient had minimal paralysis without prolonged distal motor latency; two patients had fully recovered, one within six months and the other had a relapse that is still being monitored; one patient presented with partial paralysis that partially recovered, in combination with adhesive capsulitis; one patient presented with multiple diseases along with partial SA paralysis, thus functional rehabilitation was determined to be the best course of action.

The procedure was performed with the patient supine and the ipsilateral hemithorax elevated. An 8–10 cm longitudinal incision was performed over the mid-axillary line at the level of the fifth rib. The anterior edge of the lattisimus dorsi muscle was reflected backwards. The serratus anterior branch of the thoracodorsal artery was followed distally. Once the LTN was identified, external neurolysis was performed by ligating any blood vessels crossing the nerve, and by opening the SA fascia widely to eliminate any restrictions and sharp bends [18].

Patients were released from the hospital on the day after the surgery, with no immobilization. They returned to the hospital for follow-up at 1 month, 6 months (for the ENMG measurements) and one year. Because several patients did not live near the hospital, not all of them were regularly monitored at the clinic. As a consequence, the ENMG study was performed locally and the results transmitted to us. Patients without recent visits were contacted again by telephone. The results were graded using the criteria outlined in Table 1.

To compare quantitative variables, the non-parametric Mann-Whitney U test was used, with P values less than 0.05 being considered significant. The Kruskal-Wallis test was used to compare two series of quantitative variables. Qualitative variable were compared using the Monte-Carlo test.

3. Results

The cohort consisted of 52 consecutive cases with an average patient age of 32 years (range 13–70). There were 38 men and 14 women with an average age of 32 years (range 13–60) and 36 years (range 15–70), respectively. Forty-one of the patients were right-handed (no information on 8 cases). The right side was paralysed in 45 cases (87%). Six of the seven cases on the left side resulted from a direct blow to the thorax. There were no bilateral cases. The paralysis was present for an average of 2 years (median 1 year, range 4–259 months). The paralysis was complete in 27 cases (52%) and partial in 25 cases (48%) (Fig. 2a).

The injury mechanism in 28 cases was repeated micro-trauma. The injury was sports-related in 13 cases (25%), due to an accident at home in eight cases (15%) and due to a work-related accident in seven cases (13%). A single injury episode was identified as the

![Fig. 1. Position of the distal segment of the long thoracic nerve (LTN) relative to the vascular branches of the thoracodorsal artery (TDA).](image_url)
trigger in 22 cases. In 14 of these cases (27%), it was the result of trauma to the lateral side of the chest or traction of the arm; in the eight other cases (15%) it was due to a single event, such as stretching or an unusual posture. No triggering factor was identified in the last two cases.

Thirty-six patients reported having pain. In 20 cases, this pain was isolated neuropathic pain (lateral thorax and/or posterior scapula) and in two cases the pain was due to anterior rocking of the shoulder. In six cases, the pain was from trapezius, rhomboid and/or levator scapulae muscle compensation. In seven cases, neuropathic pain was associated with compensatory muscle pain. In one case, all three types of pain were present. A pseudo-Tinel sign was present in 31 cases on the LTN course near the fifth rib; the Tinel sign was negative in 10 cases and not recorded in 11 cases.

The preoperative ENMG examination showed abnormal muscle innervation in every patient. The denervation was partial in 38 cases, complete in six cases and present but poorly recorded in eight cases. Distal motor latency was increased in 21 cases, normal in eight cases, not measurable in three cases and not recorded in 20 cases.

During the surgical procedure, isolated fascial fibrosis was found in eight cases (15%). In 30 cases (58%) it was associated with abnormal vascular findings (Fig. 2b). In five cases (10%), it was associated with abnormal muscular findings, such as SA muscle digitations forcing the nerve’s trajectory to deviate. In seven cases (13%), it was associated with muscular and vascular abnormal findings. In two cases (4%), only vascular abnormalities were present.

The average postoperative follow-up was 2.5 years (range 1 month to 6.5 years). The results were excellent in 27 patients, good in 18, fair in 4 and poor in 3. No patients experienced a worsening of their condition. Every patient experienced at least some decrease in pain and/or improvement in serratus anterior muscle function. There were no complications related to the surgical procedure itself. In 32 cases (61.5%), the scapular winging was no longer present (Fig. 2c). In 19 cases (36.5%), the scapular winging was still present, but to a lesser degree than before the neurolysis. In one case (2%), the winging was equal to the preoperative situation. This was a 60-year-old patient presenting with chronic neuropathic pain (2.5 years), who had a clear reduction in pain and was able to stop analgesic treatment 2 months after the neurolysis procedure. In patients where the paralysis was less than 18 months old, most of the results were either good or excellent (Fig. 3). The single poor result in this sub-group of patients occurred in a patient who was only evaluated by telephone.

The results relative to the presence of preoperative pain and the type of pain are shown in Table 2. Patients who did not have preoperative pain had a less chronic paralysis than those with neuropathic pain and those with compensatory muscle pain ($P=0.06$); recovery occurred most quickly, but not significantly ($P=0.23$). Patients with preoperative neuropathic pain experienced faster pain relief than patients with compensatory muscle pain ($P=0.05$); their results at the last follow-up were also significantly better ($P=0.006$). Overall, there were more excellent or good results in patients without preoperative pain or with neuropathic pain, respectively, than in patients with compensatory muscle pain ($P=0.002$).

Nine patients were treated in a rehabilitation centre: three immediately after the surgery because of significant preoperative pain; three for persistent background pain despite partial motor recovery in two patients and full recovery in the third; three because of persistent scapulothoracic dyskinesia despite recovery of motor function.

Unfortunately, two of the three patients with a poor outcome did not live near the hospital and did not receive the clinical follow-up that we would have liked to provide. In all likelihood, they would have needed to be hospitalized in a rehabilitation centre because...
of persistent pain despite partial improvement in SA function. The third patient had associated calcifications in the rotator cuff; the neurolysis procedure only led to moderate improvement.

ENMG data at the review or longest follow-up were available in 31 patients. In one patient with partial paralysis for 4 years, the analysis showed persistent signs of chronic denervation, despite scapular winging no longer being present. In all the other cases, the re-innervation was fairly extensive. In 19 cases, distal motor latency information was also available: it was normal or sub-normal in 12 cases and increased in 7 cases, but less than before the surgery.

4. Discussion

The current study presents results from a large cohort of patients who underwent surgical release of the distal portion of the LTN; this is an extension of a previous multicentre study [19]. The procedure was only performed on patients with isolated serratus anterior paralysis of mechanical origin who did not spontaneously recover their function. This injury is not very common, but has been described in several published studies. The following studies included more than 10 cases, after RTS cases and iatrogenic injuries were excluded: 211 non-operated cases for Pikkarainen et al. [20], 41 operated cases for Nath et al. [14], 27 non-operated cases for Friedenberg et al. [21], and 14 cases for Gozna et al. [15]. The aetiology in the above studies was similar in type and proportion to the one found in the current study; they also found that the condition most often occurred on the right side.

The long thoracic nerve is a thin nerve that averages 24 cm in length [12,14]. Although a few potential compression sites exist, the exact location where the nerve is being compressed remains controversial. Several studies have suggested that it is compressed at the middle scalene muscle [1,15,22,23]. In cadaver studies, the LTN was found to be stretched over the 2nd rib [15,24], with a fibrous band causing the nerve to bend sharply during shoulder abduction [24,25]. In our previous work, we observed that vascular and fibrous structures were likely to mechanically restrict the distal part of the LTN [16]. Vascular branches cross over the LTN at the lower part of the serratus anterior around the 5th rib [2]. In the current study, we found one or several intraoperative abnormalities in every patient. The LTN was restricted from moving along the thoracic wall. This restriction could be either proximal or distal [1]. The immediate pain relief felt by patients following either distal or proximal neurolysis, may be explained by the removal of tension on the nerve [14]. We did not release the LTN above the 2nd rib because we

<table>
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<th>Table 2</th>
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<td>Main outcomes as a function of the type of preoperative pain.</td>
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<table>
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<tr>
<th>Duration of preoperative paralysis (months)</th>
<th>No pain (n = 16)</th>
<th>Neuropathic pain (n = 22)</th>
<th>Compensatory muscle pain* (n = 14)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (range)</td>
<td>12 (5–39)</td>
<td>24 (4–98)</td>
<td>39 (8–259)</td>
</tr>
<tr>
<td>Median</td>
<td>9</td>
<td>13</td>
<td>18</td>
</tr>
<tr>
<td>Time to pain reduction (days)</td>
<td></td>
<td></td>
<td>p = 0.05</td>
</tr>
<tr>
<td>Mean Range</td>
<td>&lt;27</td>
<td>&lt;80</td>
<td></td>
</tr>
<tr>
<td>Degree of change (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete relief</td>
<td>86</td>
<td>43</td>
<td>p = 0.006</td>
</tr>
<tr>
<td>Reduction</td>
<td>14</td>
<td>28.5</td>
<td></td>
</tr>
<tr>
<td>No improvement</td>
<td></td>
<td>28.5*</td>
<td></td>
</tr>
<tr>
<td>Time to strength recovery (months)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Range</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;3.5</td>
</tr>
<tr>
<td>Result (%)</td>
<td>Excellent</td>
<td>62.5</td>
<td>63.5</td>
</tr>
<tr>
<td>Good</td>
<td>37.5</td>
<td>32.0</td>
<td>35.5</td>
</tr>
<tr>
<td>Fair</td>
<td>4.5</td>
<td>21.5</td>
<td>21.5</td>
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<tr>
<td>Poor</td>
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n: number of cases.

* Eight patients also had associated neuropathic pain.

* Four cases of persistent muscular pain without scapulothoracic dyskinesia with objective functional improvement and partial reduction of scapular winging.

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felt that distal release was sufficient, given that local abnormalities were likely compressing the nerve.

If the LTN is compressed proximally within the middle scalene, both the rhomboids and serratus anterior would be affected [15]. In Nath study of 50 cases of proximal neurolysis (nine in the context of PT), every patient had involvement of other shoulder muscles, evidence that the superior trunk of the brachial plexus was affected [14]. The pathology described is therefore different than the one in the current study.

Because of its location, function and role in scapulothoracic kinematics, refined grading of the serratus anterior is difficult to perform and unreliable. Evaluating the shoulder range of motion is also difficult in this context, although some authors have suggested alternative techniques [14,20]. We preferred grading the scapular winging as simply partial or complete. However, scapular winging may occur because the SA is not being activated, even when it is not paralysed. Scapulothoracic dyskinesis can be implicated right away, but is more often implicated in a patient with long-standing paralysis even when neurolysis has resulted in objective recovery of the SA. As a consequence, it is important to confirm the existence of an objective deficit and the neurogenic nature of the condition using clinical and ENMG examinations. We recommend evaluating the SA in closed kinetic chain movements to attempt to bypass any potential dysfunction and to look for transient activation of the SA. Under these conditions, complete coaptation of the scapula upon lifting the arm can be observed in a patient presenting with seemingly complete paralysis.

Our study is the first one in which the type of pain was precisely described. The pain was correlated to the duration of paralysis and the prognosis. Other than neuropathic pain related to compression and/or LTN tension, compensation by other scapula-stabilizing muscles is likely to bring about pain and muscle spasms. These problems were often found in the trapezius muscle. A postural disorder can appear and significantly impact the patient’s function. In the current study, neurolysis was highly effective at relieving neuropathic pain. Any positive effect on compensatory muscle pain took longer to manifest itself and was more random. Scapular winging and scapulothoracic dysfunction can cause subacromial impingement and acute rotator cuff injuries [3], which can also cause pain and increase dysfunction.

Although every patient received some benefit from the surgery, the ones who were operated on within 18 months of their paralysis had the best results. Beyond this time frame, the SA has lost some of its ability to recover and compensatory muscle activation has become chronic. The motor deficiency can still be reduced in this scenario, but the pain and/or scapulothoracic dysfunction may persist.

The ENMG analysis is not always a good indicator of injury severity and has no prognostic value [21]. We always perform this analysis before performing surgery to confirm the neurogenic origin and isolated nature of the SA deficit. In many cases, it also reveals increased distal motor latency.

If untreated, spontaneous recovery can be expected in 50% of cases at the most [15]. Pikkarainen reported that 8 of their 12 cases of partial paralysis due to trauma had recovered [20]. If there is no spontaneous recovery, extensive palliative measures are suggested by some authors, namely pectoralis major transfer [26–28] or scapulothoracic fusion [29], but the results are inconsistent and may not be long-lasting. Gozna et al. recommended waiting 6 months before performing surgery [15]. Pikkarainen et al. [20] recommended waiting two years before performing palliative surgery. We recommended not waiting more than six months to perform surgical release because chronic pain and compensatory muscle spasms are very disabling and hard to correct, as demonstrated in this study. If there are no signs of re-innervation in this time frame, the possibility of complete spontaneous recovery later on is low [15,19].

5. Conclusion

Isolated LTN paralysis is a rare condition that is not well known. In cases with a mechanical mechanism of injury (trauma or micro-trauma), it can be compared to entrapment neuropathy. If spontaneous recovery does not occur, neurolysis of the distal segment of the LTN very often leads to good results because it reduces the tension on the nerve and removes any compression. However, it should be performed within 18 months and before any pain appears due to compensatory muscles spasms. This is a safe and effective procedure, especially when performed within 6–12 months of paralysis. Beyond this time frame, neurolysis can still provide useful functional improvement and spare the patient from palliative surgery.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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