Laminotomy in adults: technique and results

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Abstract The objective of this study was to describe step by step our surgical technique of laminotomy and analyze our series with regard to spinal deformities (risk and predisposing factors), postoperative pain and rate of postoperative contusions. Data regarding patients who underwent our technique of laminotomy ($N = 40$, mean follow-up: 52 ms) ($N = 40$) between 2002 and 2006 were retrospectively evaluated. The technique used is illustrated in depth. Chronic pain was present in 30% with a mean score of 3/10 cm (Graphic Rating Scale). Postoperative kyphoses occurred in three patients, all below 35 years of age and with laminotomies which involved C2 and/or C7. None of these deformities required further surgical treatment because they were self-limiting or asymptomatic at a mean follow-up of 52 months. Based on the results, our technique proved to be safe and effective in terms of late deformities, blood loss, early and chronic postoperative pain and protection from postoperative accidents over the surgical site.

Keywords Laminotomy · Iatrogenic deformities · Technique · Outcomes

Introduction

In the present paper, laminotomy is defined as an en-bloc surgical division of the vertebral arch at the base of the laminae with subsequent re-positioning at the end of the procedure. Laminectomy is defined as a piecemeal removal of the vertebral arch starting from the base of the laminae without the final reconstruction. Laminotomy has become the standard approach to the spinal canal when bone decompression of the vertebral canal is not the goal of the surgical procedure [6, 9, 10, 15, 20, 27]. It is widely used to reach spinal tumors and vascular malformations [4, 9, 15, 20]. Various authors have demonstrated its efficacy and discussed its advantages in comparison with the standard laminectomy [10, 17, 25, 26, 32, 34]. Although the benefits of the laminotomy have not yet been fully demonstrated, it is appealing for the following reasons:

- Lower risk of epidural scarring;
- shorter procedure: after a short learning curve, opening of the spinal canal is much faster than in the piecemeal laminectomy;
- lower blood loss due to the shorter bone work during opening; and
- lower risks for spinal cord trauma due to accidental blows after the operation.

Whether laminotomy actually reduces the risk of delayed deformities (kyphosis, segmental instability) thanks to reconstruction of the posterior osteo-ligamentous complex, remains an open issue [5–7, 19, 21, 23, 26, 30, 32, 40]. Furthermore, a standardized technique does not exist. As for the expansive laminoplasty, each author describes his own personal technique [1, 8, 10, 11, 13, 20, 27, 33, 36]: some of these are even at the antipodes [9, 25], though all of them are currently used according to the surgeon's preference.

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The aim of the present study was to propose a standardization of the procedure, describing our surgical technique step by step and to analyze our series as regard to spinal deformities (risk and predisposing factors), postoperative pain and rate of postoperative contusions.

Patients and methods

Between 2002 and 2006, a prospective cluster of patients were submitted to laminotomy.

Including criteria were syringomyelia, epidural hematoma, vascular malformations, and non-osseous primary spine tumors, regardless of their extension.

Excluding criteria were overt spinal instability, stenosis, bone lesions, infections and malignant lesions with dural involvement.

Age and extent of the access did not play a role in the decision to perform either a laminectomy or a laminotomy.

Patient follow-up consisted of clinical interviews, plain X-Rays and MRI every 6 months. After a minimum 4-year follow-up, MRI and CT scans with reconstructions were evaluated for postoperative deformities, radiographic and clinical evidence of epidural scarring, clinical and radiographic evidence of spinal stenosis and Lhermitte-like episodes due to direct trauma to the site of surgery; the osteo-ligamentous flap was evaluated in terms of the degree of fusion, radiological status of the posterior ligaments and complications such as sequestrations, absorptions, infections or displacements.

Two weeks after the operation, all the patients answered a graphic rating scale (GRS) for a quantitative evaluation of early postoperative pain; the same test was administered at the late follow-up to assess chronic pain.

Surgical technique

Cervical laminotomy

Opening (Video 1 of supplementary material)

After a posterior longitudinal skin incision, the posterior superficial cervical fascia is exposed for a few centimeters bilaterally. At the cervical segment, the supraspinous ligament leaves its tight adherence to the spinous process of C7 to insert on the external occipital protuberance. Between C2 and C7 the nuchal ligament forms a sagittal layer of fibrous tissue which interconnects the spinous processes to the supraspinous ligament (Fig. 1). Hence, between C2 and C7, the posterior superficial cervical fascia can be cut unilaterally (on the same side as the tumor) and paramedian, preserving the supraspinous ligament (Fig. 2).

Fig. 1 The supraspinous ligament leaves its tight adherence to the spinal processes at the level of C7 (white arrows). Above this, the ligament becomes more superficial (black arrows) ending at theinion: a wide nuchal ligament (asterisk) interposes between the supraspinous ligament and the cervical spinous processes

Fig. 2 Final exposure of the cervical spine before lamintomy. The posterior superficial cervical fascia is cut unilaterally and paramedian preserving the supraspinous ligament which is displaced laterally. Note the muscular attachments on the C2 spinous process: Rectus major, Inferior oblique and semispinalis cervicis muscles

Dissection proceeds along the nuchal ligament which is progressively displaced contralateral to the tumor. The attachments of the connective plate to the spinous

processes are then skeletonized to allow exposure of both the laminae and part of lateral masses, as usual. The sub-occipital muscles originate from the spinous process of C2: if not strictly required, the spinous process of C2 with the corresponding muscular attachments should be left intact (Fig. 2).

A high-speed drill or, better, an US aspirator with a bone tip is used for the laminotomy on the side of the tumor. On the opposite side, the laminotome is used. The laminae are cut caudo-cranially following a line which passes halfway between each spinous process and zygapophysial joint, obviously preserving its articular capsule.

The interspinous ligaments at rostral-most and caudal-most levels of the laminotomy segment are cut and the flap is elevated. The osteo-legamentous complex is therefore formed by the laminae, the interspinous processes, the yellow and interspinous ligaments. It is stored in 250 cc of saline solution plus Gentamicin 80 mg/2 ml.

If the laminotomy comprises or must be extended below C7, where the supraspinous ligament become adherent to the spinous processes, these are trimmed with an oscillating saw at their distal extremity (Fig. 3).

Fig. 3 If laminotomy must comprise C7 or is extended below it, where the supraspinous ligament become adherent to its processes, the processes are trimmed with an oscillating saw at their distal extremity (at about their upper 1/3)

Closure (Video 2 of supplementary material)

Reconstruction is done using plates and screws. The cranial set can be used for this purpose. Attention must be paid to correctly shape the plates and to fix them in order not to violate the zygapophysial joints. The plates at the extremities of the flap are of utmost importance not only for securing it in place but also for guaranteeing the symmetry of the laminotomy: therefore, they must have two screws per side. The intermediate plates enforce the fixation, blocking each segment and avoiding subsidence of the flap: one screw per side is enough. If the spinous process of C7/D1 is cut to extend the laminotomy to the thoracic spine, the process can be reduced with a plate and 2 screws unilaterally.

If the interspinous ligaments are thick enough, the deeper aspect of the nuchal ligament is sutured with absorbable threaded vicryl sutures. A deeper layer of absorbable stitches brings together the muscles from both sides: each suture crosses the interspinous ligament, thus securing muscles and flap to one another (Fig. 4). A more superficial muscular layer is sutured as usual. The supraspinous ligament is sutured to the superficial cervical fascia, preferably with a running suture. A subcutaneous layer is always performed with reversed knots. The skin is closed

Fig. 4 Cervical laminotomy: closure. Reconstruction is made with plates and screws. The intermediate plates can be shorter. A deeper layer of adsorbable stitches will approximate the muscles from each side: each suture will cross the interspinous ligament securing muscles and flap to one another. A more superficial layer is performed, fixing the muscles as usual. The supraspinous ligament is sutured with the superficial cervical fascia. A subcutaneous layer is always performed with reverse knots

Fig. 5 Thoraco-lumbar laminotomy: opening. The muscles are dissected away from the lateral aspects of the spinous processes and the laminae until the facet joints are exposed. The supraspinous and interspinous ligaments at rostral-most and caudal-most levels of the laminotomy segment are cut

with rapid absorbable vicryl sutures or with nylene, when appropriate.

Thoraco-lumbar laminotomy

Opening

Posterior longitudinal skin incision. Two incisions are made in the posterior thoracolumbar fascia along with the supraspinous ligament preserving its integrity. The muscles are dissected away from the lateral aspects of the spinous processes and the laminae until the facet joints are exposed. The supraspinous and interspinous ligaments at rostral-most and caudal-most levels of the laminotomy segment are cut (Fig. 5). The osteotomy does not differ from the one previously described.

Closure (Video 3 of supplementary material)

The osteo-ligamentous flap is repositioned according to the same technique previously described. Absorbable vicryl

Fig. 6 Thoracolumbar laminotomy: closure. Reabsorbable vicryl sutures reconnect the supraspinous ligament using a “Smead-Jones”-like technique. Muscles are approximated with U-shaped stitches with their deeper branches which cross the interspinous ligament and their superficial branches which run just below the supraspinous ligament

sutures re-connect the supraspinous ligament with “Smead-Jones”-like technique: once positioned, the suture will resemble a figure of eight (Fig. 6). Suturing the ligamenta flava is not necessary, in our view. Muscles are approximated with U-shaped stitches with their deeper branches crossing the interspinous ligament and their superficial branches running just below the supraspinous ligament (Fig. 6). The thoracolumbar fascia is closed preferably with running sutures on each side. A subcutaneous layer always precedes the skin closure.

Results

40 patients were treated. Mean age was 41 (range 19–69). Patients were grouped in Table 1 according to their pathologies. The mean extent of laminectomy was 2 levels (range 1–6). Mean blood loss was 210 cc. Patients with pathologies above D2 represented 27.5% of the series (11 pts).

Early postoperative pain ranged from 1 to 5/10 cm according to the GRS (mean: 3/10 cm).

Table 1 Patients with pathologies approached by laminotomy (*N* = 40)

Astrocytoma	8 (20%)
Cavernoma	3 (7.5%)
Epidural hematoma	7 (17.5%)
Ependymoma	11 (27.5%)
Hemangioblastoma	2 (5%)
Schwannoma	5 (12.5%)
Syringomyelia	2 (5%)
Vascular malformations	2 (5%)

At a mean follow-up of 52 months, chronic pain was present in 12 patients (30%) with a mean score of 3/10 cm. Five of these harbored cervical lesions with evidence of moderate post-operative kyphosis; three of them were operated on for thoracic lesions; the remaining four cases were already scoliotic, had been operated on the lumbar region and had no late deformities.

Kyphoses after cervical and cervico-thoracic laminotomies occurred in three patients, all aged below 35 years (7.5% of the whole group, 27.3% of patients with laminotomies above D3). The level of their laminotomies was C1–C4, C2–C5 and C7–D3, respectively. No kyphosis occurred in cases operated on below D3, even in cases with wide access (range: 1–6 levels, mean: 2 levels). None of these deformities required further surgical treatment because they are either self-limiting or asymptomatic at the moment.

There was no radiographic evidence of pseudoarthrosis, spondylosis, canal stenosis, epidural scarring or absorption. Neither Lhermitte's sign nor pseudomeningocele occurred in the group. Seven patients have been re-explored for recurrent tumors. The interspinous and supraspinous ligaments developed a tight fibrous tissue which guaranteed the continuity of the ligament. The tissue was well developed as early as 9 weeks later. At each lamina level there was an ossification along with the plate even if the plate itself could be dissected from the bone underneath once the screws have been removed.

Discussion

Some confusion exists regarding the correct term to be used for laminotomy [38]: several studies in the literature refer to it as replacement laminotomy, non-expansive laminotomy, osteoplastic laminotomy, laminoplasty, open-door laminoplasty, non-expansive laminoplasty, “en bloc” laminoplasty, recapping laminoplasty, etc [3, 7, 10, 13, 16, 20, 32, 36]. The term “laminotomy” seems more appropriate to us, as also suggested in a brilliant commentary by Sonntag in 2000 [38] mostly for its analogy with the

nomenclature used in cranial surgery (craniectomy/craniotomy/cranioplasty).

There is still no definite evidence that laminectomy is followed by clear impairment of spinal stability in adults [28] as this condition mainly depends on the facet joints (also known as zygapophysial articulations) [18, 30]. Therefore, every effort should be made to preserve the facet joint capsules when a laminectomy is planned [7, 32, 35]. Nevertheless, a reconstruction of the whole posterior complex, respecting the normal anatomy, should always be pursued. On the basis of this consideration, we began to employ the laminotomy to all patients operated on for intradural spinal tumors, spinal vascular malformations, syringomyelia and selected kinds of traumas. We did not enroll patients with severe osteoarthritis and infections, to avoid adding a potential bias towards postoperative instability and chronic pain. At follow-up, these patients presented a satisfactory fusion of the osteo-ligamentous flap with the spine: indeed, in some cases, the level of operation could barely be identified on MR images (Fig. 7a–b).

Nevertheless, laminotomy is not yet the standard approach for pathologies of the spine and spinal cord not requiring bone decompression [4, 6, 9, 15, 17, 20, 25, 26, 30, 32].

Moreover, there are plenty of techniques in the literature with corresponding tips and tricks [1, 3, 6, 8–11, 13, 16, 20, 27, 29, 33, 35, 36]. Cochrane suggests placing drill holes through the spinal processes to facilitate approximation of the paraspinal muscles and elevating the laminal flap out of the spinal cord [8]. In our opinion, sutures through the interspinous ligaments suffice for facilitating approximation of the muscles; we keep the laminar flap firm with the plate and screws technique so there is no need to delegate this task to the muscles which, on the contrary, held down by the laminar flap avoiding the formation of dead spaces. Finally, sutures placed through the ligamentum flavum can be omitted [8]. Nevertheless, the Cochrane technique is useful in cases where the supraspinous ligament is too thin to place stitches with an appropriate strain.

Some authors implemented a pedicled laminotomy, preserving the attachment of the ligaments cranially in order not to reduce the vascular supply to the laminar flap [8, 10]. Even if this technique is feasible, we are skeptical about its usefulness for the following reasons: the major part of the blood supply comes from the muscles with the lateral feeders which are interrupted using both techniques; the non-subperiosteal division of paraspinal muscles implies a greater blood loss; in any case the supraspinal and interspinous ligaments are interrupted at the caudal site and this places the two techniques on the same level from a biomechanical point of view; the flap must often be lengthened (always in the thoracic tract) so that the surgical field is not narrowed; the flap remains in the surgical field

Fig. 7 **a** Preoperative Gd-enhanced T1 W MRI of a cauda equina ependymoma. **b** In the postoperative T2W MRI the fibrous scar along with the cut of the supra and interspinous ligaments is the only indicator of the level of laminotomy

during the operation, instead of being kept in saline solution with antibiotic; the results of the two technique are similar in terms of the healing process and the absence of complications [1, 3, 4, 6–11, 13, 15–17, 20, 25–27, 29, 32, 33, 35–37].

Asazuma and Hida [3, 16] reported their experience with the 90 degree rotational laminoplasty. The approach is only feasible for the lower thoracic and lumbar spine. As the Authors themselves say, this is not a physiological reconstruction: the lamina lie along a paramedian oblique plane and the muscle layers cannot be reconstructed perfectly. The main aim is to enlarge the spinal canal: we believe that this can also be achieved using longer plates, as also described by Casha [7].

Kim et al. [21] described a fascinating myoarchitectonic approach to the cervical spine. This consisted of splitting the spinous processes and cutting the spinolaminar junctions and the laminae just medial to the zygapophyseal capsules. The Authors cut the nuchal ligament rather than displacing it (as we propose) reconstructing its three layers during closure. This technique was created to treat cervical myelopathy and, therefore, is not applicable to the entire spine and is not feasible for intradural lesions because of the limited access. Although a correlation between pain, deformities and accesses comprising C2 or C7 levels is well documented and acknowledged, there is still no consensus regarding the effective role of the paraspinal muscle

attachments at C3–C6 on postoperative complications: for example, Sani [30] stated that he could not find any link between cervical muscular atrophy and postoperative kyphosis.

On the opposite extreme, we found some Authors who trim the spinous processes to prevent perforation of the fascia after closure [9]. This technique stresses the need for posterior fusion of the flap to guarantee protection against future local trauma. However, it does not take into account the importance of reconstructing the ligaments to avoid spinal deformities, maybe due to the lack of definite data on this topic. We were able to find only one statistical analysis on different pediatric populations in the literature [26]. Our series provides data on adults with over 4 years of follow-up. Longer follow-up would be desirable to confirm our results, but 52 months in the adult population seems to be a good end-point, as Raab states in his discussion [24, 26]. We think that the essence of the laminotomy lies in the preservation of the spinous processes as well as the interspinous and supraspinal ligaments, besides the laminae. Only if all these structures are reconstructed, can a complete reconstruction of the posterior column be obtained.

We applied two different techniques in approaches to levels below D1 and to the cervical spine, respectively. This reflects the differences between the behavior of the supraspinal ligament and the wideness of the paravertebral

muscle insertions on the posterior aspect of the vertebrae (thinner in the cervical region). Moreover, the spinous process of C2 is especially important owing to its attachments to the suboccipital, the splenius capitis and semispinalis cervicis muscles [7, 12, 21, 32]. The suboccipital muscles contribute to occipito-cervical junction stability during movement, while the paraspinal muscles provide lever arms and actuators important in the dynamic tension band which maintains cervical lordosis and confers stability [5, 7, 21, 32]. The spinous process of C7 is also important because it is the point where the supraspinous ligament ceases to be tightly adherent to the spinal processes and becomes more superficial: a wide nuchal ligament interposes between it and the cervical spinous processes (Fig. 1) [7, 21, 29]. There is no need to cut the supraspinal ligament when a posterior cervical access is planned: it can be displaced to one side of the surgical field; if extension toward the thoracic region is needed, the spinous processes are trimmed at their upper third with the supraspinous ligament still attached (Fig. 3). The integrity of the posterior tension band will concur in maintaining the stability of the spine [5, 7, 21, 29, 40]. Problems remain in cases where C2 is comprised during the laminotomy. In our series, in the only case with a kyphosis in the cervicothoracic junction, the cervical extension technique described above to preserve the supraspinous ligament was not feasible: as the laminotomy was from C7 to D3, we just cut the supraspinous ligament above and below. On the other hand, our results in this isolated case do not allow further speculation.

In thoracic and lumbar operations, where the supraspinous ligament must be cut, we try to reconstruct it by applying long-term absorbable sutures (Vicryl). In patients who underwent a reoperation we always found that a tough fibrous tissue developed along the suture bridging the two extremities of the ligament. We did not find it necessary to suture the ligamenta flava because it has not been demonstrated that they play a role in the stability of the flap or of the spine. The way we suture muscles during closure aims at keeping muscles adherent to the laminae and spinous processes and at facilitating the alignment of the most superficial layer to the apex of the spinous processes. These tips should allow a more physiological reattachment of the muscles [7].

Postoperatively, patients are immobilized using appropriate soft orthoses for just 4/5 days, partially agreeing with Abbott who does not immobilize his patients at all, as this would interfere with rehabilitation [1]. We rather found that a short external immobilization avoids overloading of the healing muscles, thus reducing postoperative pain [14, 21, 40].

The time required for laminotomy is considerably shorter than that for traditional piecemeal laminectomy.

When the bone is replaced, the operative time approximates that of traditional laminectomy [1, 8].

Our results regarding epidural scarring confirm what emerges from the Literature. Wiedemaeyer [36] stated that epidural scarring was limited in his series of osteoplastic laminotomies. Hara concluded that laminoplasty might be a useful procedure for decreasing local epidural scarring, which could be responsible for arachnoiditis or re-stenosis and might lead to an exacerbation of neurological symptoms [13]. Kawahara, Hida, Benglis [20] all confirmed that laminotomy actually reduced the risk of epidural scarring in their series of laminotomies. Beside these clinical experiences, In 2000, Yucesoy [39] published convincing experimental evidence about the barrier effect of the laminae in preventing the post-laminectomy membrane. Sani [30] analyzed the clinical significance of the post-laminectomy membrane or epidural scarring: in contrast to Hara, they concluded that these were never responsible for any neurovascular compression. Although if a fibrous post-laminectomy membrane cannot compress the neighboring neurovascular structures, at the same time, it does not offer the same resistance as the bony posterior arches to blunt trauma. Laminotomy seems to be effective in reducing fibrous tissue formation upon the dura mater and nerve roots, while maintaining a protective role to blunt traumas at the laminotomy site. Using a questionnaire we analyzed the symptoms of patients after occasional blunt trauma to laminotomy sites. No patient referred to Lhermitte's sign after local traumas [22, 31].

Kyphoses after laminotomies above D3 occurred in 27.3% of patients. They were all younger than 35 and bone removal had involved the laminae of C2 and/or C7. No kyphosis occurred in cases operated below D3, even in those with wide access (range: 1–6 levels, mean: 2 levels). We compared the present series with our previous experience using laminectomy (40 patients randomly chosen retrospectively, unpublished data). Postoperative kyphosis had an overall incidence of 38% while it occurred in 63% of laminectomies above D3.

Sani [30] stated that the major part of post-laminectomy segmental instability and kyphoses seldom necessitate a surgical stabilization because they are rarely responsible for neurological deterioration. This Author did not consider muscular stiffness and chronic pain due to deformities, as instead highlighted in other series [21, 40]. Although these complications are not fatal, they can significantly impair the quality of life [40]. We did not find any thoracic/lumbar deformities. Age seems to have a primary influence on the risk of late deformities, as also stated in literature [22, 26]. In fact, problems still exist with higher approaches when the patients are younger than 35 years, in spite of the absence of complications directly related to the flap (displacement, non-fusion, absorption). C2 and the cervicothoracic junction

seem to be critical sites, although statistical correlations are still not feasible due to the scarcity of our patient.

Pseudoarthrosis at the site of laminotomy is a possible risk because the technique makes bilateral ditches of few millimeters wide on the lamina although we never observed this complication. In patients who underwent re-operation we found osseous bridges along with plates and tight fibrous tissue in cases where ossification was incomplete. It is worth noting that ossification began along with the plates. Volumetric CT scan with oblique and 3D reconstructions can be also useful for determining whether the flap is not displaced and has enough osseous bridges, if any, to make it stable [16].

We chose the GRS for the outcome assessment. The GRS is a self-reporting measurement, reflecting the subjective feeling associated with the pain. It is a very good indicator of the impact of pain in the quality of life of the patient. We think that GRS isolates pretty well the effect of the approach on the patient, better than quality of life questionnaires which may be biased by the pathology itself (e.g. high-grade astrocytoma vs cavernoma) [2]. The incidence of chronic pain was 30% and the reported intensity was low (3/10 cm) at GRS for chronic pain. Laminectomy series usually report higher values [15, 18, 24, 34, 37]. Laminotomy offers the same exposure of laminectomy while aiming to the preservation of functionally important structures which are left untouched or at least reconstructed. Our results show a low prevalence with mild intensity of pain in laminotomies without a comparison with a corresponding group of laminectomies: therefore, it lacks of statistical significance. Nevertheless, similar experiences present in the Literature tend to confirm that soft tissue trauma caused by the approach has limited functional sequelae: for example, Kato analyzed the effect of preservation of C2 muscular attachments on postoperative pain [19]. They concluded that this caution actually reduces postoperative pain even in comparison with patients in whom the C2 muscular complex was reconstructed on closure. They also stated that detachment of the nuchal ligament and muscles from C7 does not lead to increase in postoperative pain if the muscle insertions are reconstructed during closure [19].

Conclusion

Our technique of laminotomy seems to be safe and effective in spine surgery when bone decompression is not the surgical goal and when there are no oncological contraindications.

C2 and C7 levels still represent a technical challenge as their involvement in the approach implies a higher risk of late deformities.

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Conflict of interest None.

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