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TECHNICAL NOTE

Transpedicular 3D endoscope-assisted thoracic corpectomy for separation surgery in spinal metastases: feasibility of the technique and preliminary results of a promising experience

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Abstract

Surgery for spinal metastases has undergone multiple transformations in terms of surgical technique. The need for a more aggressive surgical strategy for local control of the disease, given the advances in radiosurgery and immunotherapy, has met the incorporation of many different technological adjuncts. Separation surgery has become one of the main targets to achieve for surgeons in the treatment of spinal metastases. In this paper a prospective series of 3D endoscope-assisted transpedicular thoracic corpectomies is described. Adult patients with a diagnosis of single-level thoracic metastases requiring surgery for epidural compression were included. Data recorded for each case concerned patient demographics, surgical technique, clinical, radiological and surgical data, intra- and postoperative complications, follow-up. The goal of this study was to verify the achievement of separation surgery with this technique, while confirming the safety and feasibility of the procedure. A total number of nine patients were treated from January to April 2019 with a 3D endoscope-assisted procedure. A circumferential bilateral decompression was achieved in seven cases, while monolateral in the other two. A proper separation between the tumor and the spinal cord was achieved in all cases as confirmed by imaging. Axial pain always improved after the procedure as well as neurological functions, when compromised before surgery. No intra-operative and postoperative complications were recorded. Mean hospital stay was 4 days after surgery with early mobilization. At last follow-up no local recurrences were registered. According to preliminary results, the transpedicular 3D endoscope-assisted approach for corpectomies appeared to be a safe and effective technique to achieve proper circumferential decompression and valid separation surgery in thoracic metastases, potentially decreasing the need for costotransversectomy.

Keywords Endoscopic corpectomy · Separation surgery · Spinal metastases · Transpedicular approach · Thoracic spine

Introduction

Surgery for spinal metastases has undergone multiple transformations in terms of surgical technique [1–3]. Up to the 1990s, the main surgical approach for epidural disease was a simple posterior bony decompression with a bilateral laminectomy as an alternative to primary external-beam radiation therapy (EBRT). In 2005, Patchell et al. published a landmark trial [4] demonstrating that a surgical circumferential decompression of the spinal cord with postoperative EBRT had significant benefits in terms of functional outcomes. Their findings were later confirmed by other authors [5]. Furthermore, the typical poor prognosis given to these patients has shifted to a more optimistic outlook because of advances in radiosurgery and immunotherapy [2, 6]. That is why the importance of a surgical approach grew together with technological innovation. The need for a more aggressive surgical strategy to achieve a local control of the disease and enhance postoperative radiotherapy has met the incorporation of many different technological adjuncts to improve surgical efficacy. In this paper, a series of 3D endoscope-assisted transpedicular thoracic corpectomies is described. This technique represents an innovative and promising way to improve tumoral resection, achieve a proper separation surgery [2], and therefore offer the

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possibility of performing adequate radiation therapy, while potentially reducing the risks related to other surgical approaches such as costotrasversectomy.

Materials, methods, and surgical technique

Study

This paper presents the preliminary results of a prospective study. From January 2019, the authors performed 3D endoscope-assisted procedures to treat metastasis of the thoracic spine with vertebral body involvement and epidural compression at the Neurosurgical Department of the "Città della Salute e della Scienza" in Turin (Italy). Adult patients with a diagnosis of single-level thoracic metastases requiring surgery for epidural compression were included. The availability of an adequate preoperative imaging (both MRI and CT scan) was considered mandatory for inclusion. Patients operated in an emergency setting were excluded, as were patients with more than one level requiring decompression.

Data recorded for each case included: sex, age, ASA score according to the American Society of Anesthesiologists, type of tumor, spinal instability neoplastic score (SINS) [5], grade of epidural compression according to the epidural spinal cord compression scale (ESCC) [7], pre-op and post-op numerical rating scale (NRS) for axial pain, pre-op and post-op (last follow-up) neurological status according to American Spinal Injury Association(ASIA) impairment scale (AIS), thoracic level, extent of corpectomy, type of decompression, type of instrumentation, graft placement, duration of the procedure, blood loss, intra- and postoperative complications, and time of follow-up. The goal of this study was to verify the achievement of separation surgery with this technique, while confirming the safety and feasibility of the procedure. Total corpectomy was defined as the removal of more than 95% of the vertebral body confirmed on a postoperative CT; partial corpectomy was defined as the removal of less than 95% of the vertebral body. Total replacement of the vertebral body was performed in case of significant anterior column destruction (lytic metastases involving more than 50% of the body). In case of lesions involving less than <50% the exeresis aimed to remove only the lytic part of the metastases ensuring also a proper decompression. Bone graft was placed in case of total replacement of the body or in case of partial corpectomy if a life expectancy above 1 year was estimated. Decompression was defined as circumferential bilateral when bony and ligamentous structures together with tumor tissue were bilaterally removed to free the whole circumference of the spinal cord. When the procedure approached, the vertebra removing the lamina, the pedicle, the transverse process, and the affected body only from one side the decompression was defined circumferential monolateral. The choice between the two approaches was made by senior surgeons according to the compression of the spinal cord given by the tumor as recorded on pre-op imaging. The separation between tumor and spinal cord, together with the extent of intralesional exeresis, was confirmed with a postoperative CT scan and a 3-week post-op MRI. Clinical and radiological information was obtained at time of admission and at follow-up clinic evaluation by fully trained neurosurgeons of the Department.

Consent was obtained to use clinical information for research purposes. Our work is coherent with the ethical standards proposed in the Helsinki declaration of Human Rights.

Surgical technique

"Open" step

Intraoperative neuromonitoring (IONM) was used during the procedures. Carbon-fiber reinforced pedicle screws (Carboclear™, produced by CarboFix Orthopedics® Ltd., Herziliya, IL, USA) were always placed two levels above and below the surgical metastatic vertebra. Then, to achieve a bilateral circumferential decompression, a spinosectomy with bilateral laminectomy, transversectomy, and artrectomy was performed, with complete removal of the ligamentum flavum at the chosen level. A 5 mm high speed diamond drill was used to reduce the thickness of bony structures before proceeding with Kerrison rongeurs. A dry drilling with minimal irrigation helped in reducing the bleeding by the tumor obtaining a hemostatic effect, especially in case of posterior pathological involvement. The pedicles were then removed with high-speed drilling following the road given by their inner trabecular composition and then removing the cortical shell with bony rongeurs (Fig. 1A-B-C). The corresponding nerve roots were first clipped and then coagulated and cut (Fig. 1D). The transpedicular corpectomy was then performed with a combination of drilling and pituitary rongeurs without incising the posterior longitudinal ligament (PLL) (Fig. 1E). After having reached the central region of the posterior third of the vertebral body from both sides, the 3D endoscope was used to complete the corpectomy removing the tumor on the ventral side of the dural sac and reaching the deeper aspect of the vertebral body.

Endoscopic step

A 5 mm 0° and 30° rigid 3D endoscope with a working length of 15 cm (VSiii system, Visionsense, Philadelphia, PA, USA) was inserted in the cavity, held manually by the assistant from both sides of the vertebral body alternately through both pedicles, in order to assist in the visualization of residual tumor reaching the PLL and the ventral dural sac from its rostral to its caudal extension. Surgical resection proceeded from the contralateral side using micro curettes, micro rongeurs, and micro

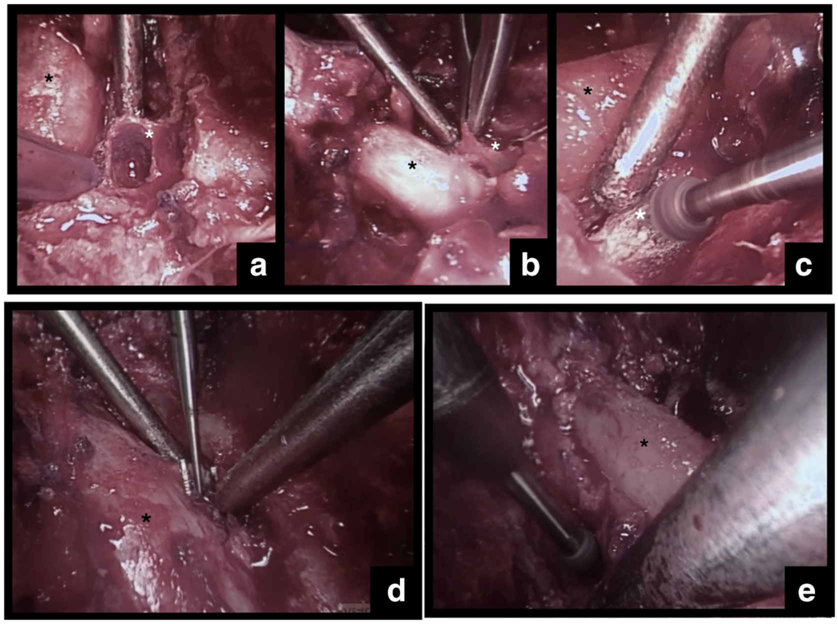

Fig. 1 The inner trabecular composition of the pedicle was removed with high-speed drilling for pediculectomy **(A).** Then, the cortical shell was resected with rongeurs **(B)** gaining access to the vertebral body **(C)**. Nerve roots were first clipped and then coagulated and cut **(D).** The corpectomy was performed with a combination of drilling and pituitary rongeurs without incising the posterior longitudinal ligament (PLL) **(E).** After having reached the central region of the posterior third of the vertebral body from both sides, the 3D Endoscope was used to complete the procedure **(E). Key**: white asterisk, pedicle; black asterisk, dural sac

dissectors (Fig. 2A-B). In order to proceed with the resection of the tumor located ventrally to the dural sac, the 30° endoscope ensured a proper vision without the need for spinal cord gentle retraction or manipulation. The resection of deeper parts of the vertebral body was mostly achieved with the 0° endoscope. Neuronavigation (Brainlab AG, 81829 Munich,Germany) was used, based on an intraoperative CT scan (Bodytom, Samsung, Danvers, MA 01923 USA) and helped confirming the extent of resection (Fig. 2C). The discs above and below the corpectomy level were identified using a Penfield no. 4 dissector and incised with a no. 15 blade knife. The discs were removed only in the parts adjacent to the resected body and the end plates of the levels above and below were exposed (Fig. 2D). At the end, the PLL was detached from the dura with dissectors and resected to ensure a complete ventral removal of the tumor and to avoid tension on the dura (Fig. 3). The use of the 0° and 30° endoscope ensured a full vision of the vertebral body (Fig. 4). In some cases a cadaveric bone graft was placed to replace the vertebral body.

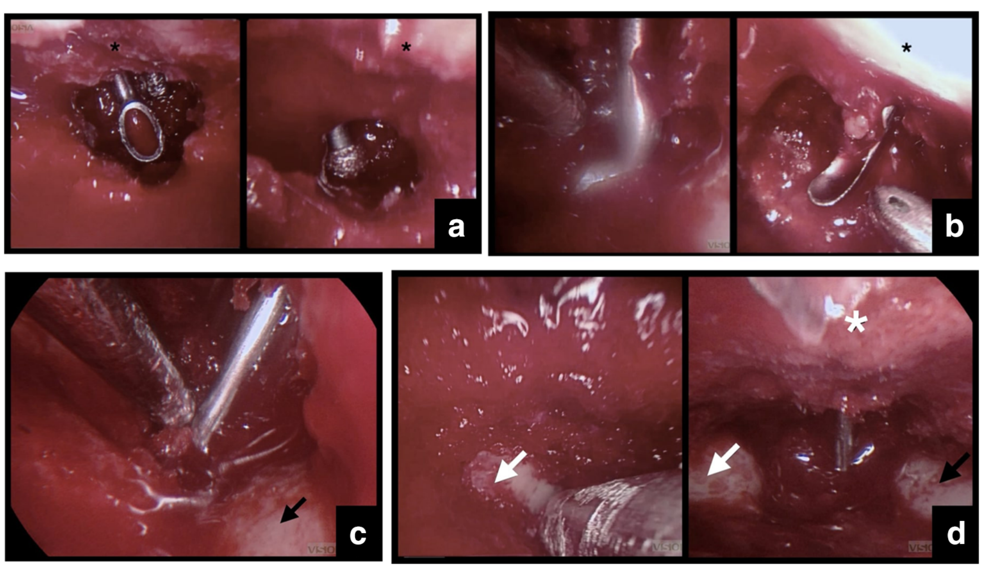

Fig. 2 Endoscope-assisted corpectomy. The endoscope was inserted in the cavity, held manually by the assistant from both sides of the vertebral body alternately through both pedicles. Surgical removal proceeded from the contralateral side using micro-curettes, drilling, micro rongeurs and micro dissectors **(A,B).** Margins of exeresis were checked with neuronavigation (pointer on the right). Discectomy was performed to expose endplates **(C).** Caudal endplate (left). At the end of the procedure both endplates were exposed (right) **(D). Key**: black asterisk, ventral dural sac; black arrow, cranial vertebral body endplate; whit arrow, caudal vertebral body endplate; white asterisk, posterior longitudinal ligament (PLL) under ventral dural sac

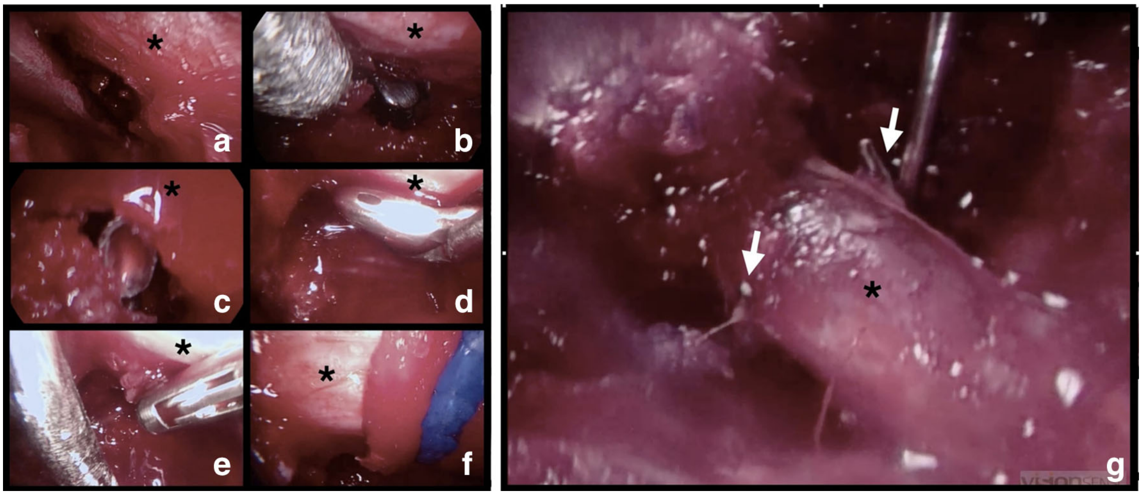

Fig. 3 The PLL was detached from the dura **(A)** with dissectors and resected **(B)** to ensure a complete ventral removal of the tumor **(C,D,E)** and to avoid tension on the dura **(F).** End of the procedure after corpectomy. Circumferential decompression of the spinal cord **(G).** **Key**: black asterisk, ventral dural sac; white arrows, nerve roots clipped

In some cases of mono-lateral involvement, the procedure was achieved with a unilateral approach preserving the contralateral side. Once reached the vertebral body after the removal of the pedicle, the assistant inserted a 30° endoscope from the rostral aspect of the body following the direction of the upper endplate, in order not to hinder the surgeon's movement and to maintain a safe reference.

Results

The results have been summarized in Table 1 and 2. A total number of nine patients were treated from January to April 2019 with a 3D endoscope-assisted procedure. In eight cases, a partial corpectomy was performed (Fig. 5). A circumferential decompression (Fig. 6) was achieved in all cases (bilateral in seven cases, while monolateral in the other two). In all cases, fixation was achieved with carbon fiber-reinforced pedicle screws. In four cases, heterologous bone was used as graft after the intralesional exeresis (Fig. 7). The mean duration of the procedure was 260 min (range 180–310 min) while the mean blood loss was 580 ml (range 455–825 ml). IONM highlighted improvements of motor evoked potentials (MEPs) at the end of the procedure in patients with neurological deficits before the procedures (Table 1, patients 3,6,7,8,9). In only one case, a temporary decrease (<50% in amplitude) in MEPs was recorded during ventral decompression and dealt with a "stop and go" strategy, without clinical implications. Mean follow-up registered was 6 months after surgery (range 4–8). Radiotherapy was performed 3–4 weeks after surgery. In all cases, the intraoperative CT scan was used together with neuronavigation to facilitate intralesional exeresis and confirm surgical margins within the body during the procedure. A proper separation between the tumor and the spinal cord was achieved in all cases as confirmed by imaging. Axial pain always improved after the procedure as well as neurological functions, when compromised before surgery. No intraoperative and postoperative complications were recorded. Mean hospital stay was 4 days after surgery with early mobilization. At last follow-up, no local recurrences were registered. Spinal stability was preserved at the last follow-up (then after post-op radiotherapy). No hardware-related complications were registered (breakage or loosening of the screws, pull-out, infections). No failure of bone grafts were observed.

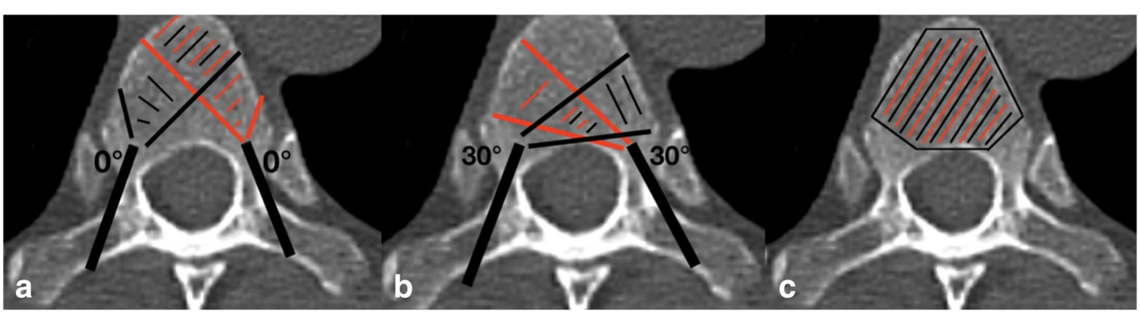

Fig. 4 Schematic field of view of the 0° **(A)** and 30° **(B)** endoscope after the open step. The hexagon **(C)** represents the full overview of the vertebral body ensured by the endoscope

Table 1 Patients data

Patient	Sex	Age	ASA score	Tumor	Level	SINS score	ESCC	NRS pre	NRS post	AIS pre	AIS post
1	M	62	2	Lung	T11	10	2	8	2	E	E
2	F	63	2	Lung	T6	8	2	7	2	E	E
3	M	52	2	Melanoma	T9	10	2	7	2	D	E
4	M	58	3	Lung	T8	9	2	8	3	E	E
5	M	65	2	Lung	T4	9	2	8	2	E	E
6	F	70	2	Colon	T11	15	3	9	3	C	E
7	F	58	2	Breast	T3	13	3	8	1	C	E
8	M	50	2	Colon	T4	13	3	8	2	C	D
9	M	51	3	Kidney	T5	11	2	8	3	D	E

Discussion

Background

Spinal metastases constitute a well-known oncologic challenge. The introduction of targeted therapies revolutionized the clinical scenario improving, above all, patients' overall survival and then revealing an exponential rise in the incidence of spinal metastasis diagnosis requiring treatment [6]. Palliation still remains the goal of treatment for the majority of these patients, aiming to achieve long-term local control, preserve or restore neurological function [7–11] ,improve axial pain, and ameliorate health-related quality of life (HRQOL). The current treatment algorithm has moved away from the historical scoring systems of Tomita and Tokuashi [12, 13], mostly estimating survival of patients, to a more comprehensive approach including the major advances obtained in the new era of spinal oncology: the development of spinal stereotactic radiosurgery [14–18]; the introduction of a validated concept about spinal instability (SINS score) [19]; the introduction of minimal-invasive techniques and separation surgery [1, 2, 20–23]; and the development of individualized targeted therapies [6, 24]. After the algorithm of Gasbarrini and Boriani, which included for the first time the evaluation of the new advances in spinal oncology for the management of patients with metastatic spine disease [25], Laufer et al. developed in 2013 the NOMS framework [26], incorporating new technological tools, surgical techniques, and advances in radiosurgery and systemic treatments [2]. In order to better provide a comprehensive assessment of new concepts for the treatment of spinal metastases The term NOMS includes the four cornerstones of management: neurologic, oncologic, mechanical, and systemic assessments. In the decades before the coming era of the aforementioned strategies, surgery for spinal metastases was characterized by standardized posterior decompression approaches and traditional radiotherapy or, in very selected cases, aggressive cytoreductive procedures such as en bloc spondilectomy. [2]

Separation surgery and the advantages of an endoscope-assisted procedure

After the introduction of SSRS, a new oncological concept of surgical planning arose. While en bloc excision still remains a goal in cases of long-term survivors with single metastasis and a favorable systemic profile (or, on the contrary, no chance for other treatments), for the majority of patients, the best strategy has become the hybrid combination of surgery and SSRS [1, 3]. The term "separation surgery" describes the need for a circumferential decompression of the spinal cord and the nerve roots in order not only to preserve or restore neurological function but also to create an ablative target and a safe distance between the tumor and the spinal cord optimizing SSRS treatment [2]. When a portion of the clinical target volume (CTV) receives less than 15 Gy, SSRS treatment could cause failure in local control of the disease. Since it is not possible to safely deliver this dose to the entire tumor margin if there is no distance between the tumor and the cord, a surgical separation is highly needed in case of epidural compression [27, 28]. Laufer et al. demonstrated the safety and effectiveness of SSRS following separation surgery in a retrospective review of 186 cases [21]. No impact on control of disease of the traditionally considered radio-resistant tumor was found, given the high-dose treatment delivered by SSRS. The degree of preoperative epidural compression did not correlate with outcomes. These results have been confirmed in the last years by other studies [2, 22, 23]. In this revolutionary scenario, a significantly high risk of recurrence and symptomatic cord compression has been found in patients whose circumferential decompression was not sufficiently achieved when needed: the reconstitution of the thecal sac seemed then to be mandatory to allow for a proper local control [29] of the disease and therefore the surgical step gained a key role in this complex framework.

The development of circumferential decompressive procedures is historically due to the poor outcomes related with simple bilateral laminectomies. Anterior decompression was initially achieved through a transthoracic or retroperitoneal

Table 2 Surgical procedures

Patient	Sex/age/tumor	Level	Extent of corpectomy	Type of decompression	Type of instrumentation	Interbody graft	Length of the procedure (min)	Blood Loss (Ml)	Complications	Length of hospital stay (Days)	Time of follow-up (months)	Separation surgery
1	M / 62 / lung	T11	Partial	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	Heterologous bone	245	550	None	4	8	Achieved
2	F / 63 / lung	T6	Partial	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	Heterologous bone	260	455	None	4	8	Achieved
3	M / 52 / mel-anoma	T9	Partial	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	None	310	670	None	5	7	Achieved
4	M / 58 / lung	T8	Partial	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	None	285	720	None	4	7	Achieved
5	M / 65 / lung	T4	Partial	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	None	205	480	None	5	6	Achieved
6	F / 70 / colon	T11	Total	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	Heterologous bone	295	520	None	4	6	Achieved
7	F / 58 / breast	T3	Partial	Circumferential Bilateral	Carbon fiber-reinforced pedicle screws	Heterologous bone	250	540	None	4	6	Achieved
8	M / 50 / colon	T4	Partial	Circumferential Monolateral	Carbon fiber-reinforced pedicle screws	None	310	465	None	5	5	Achieved
9	M / 51 / kid-ney	T5	Partial	Circumferential Monolateral	Carbon fiber-reinforced pedicle screws	None	180	825	None	3	4	Achieved

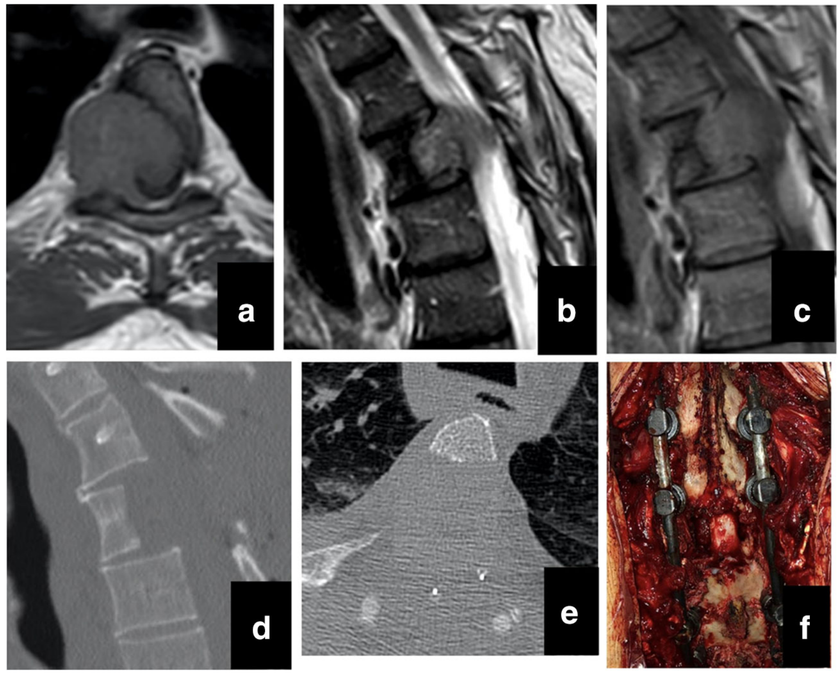

Fig. 5 Male, 65 years old (Patient 5), T4 lung cancer metastases (adenocarcinoma) (A,B,C). No neurological impairment. A partial corpectomy was performed after carbon fiber pedicle screw fixation (D,E,F)

approach [30–33], with the need for a second procedure to ensure posterior fixation.

Many patients with spinal metastases suffer from a poor general health status. In many cases, surgeons have to face medical comorbidities, previous surgery, or previous radiation therapy making these patients not real candidates for an anterior approach resulting in a high complication rate [34]. Indeed, the popularity of posterior and posterolateral approaches grew because of the lower rate of complications compared to anterior approaches. Lubelsky et al. described a mean complication rate of 39%, 17%, and 15%, respectively, for thoracotomy, lateral extracavitary, and costotransversectomy. The thoracotomy approach had the highest reoperation (3.5%) and mortality rates (1.5%) [35]. The possibility to perform anterior reconstruction and a transpedicular screw fixation in the same setting with an acceptable rate of complications made the posterior approach (both costotransversectomy or the transpedicular approach) gain a key role in spinal metastatic surgery [36–38].

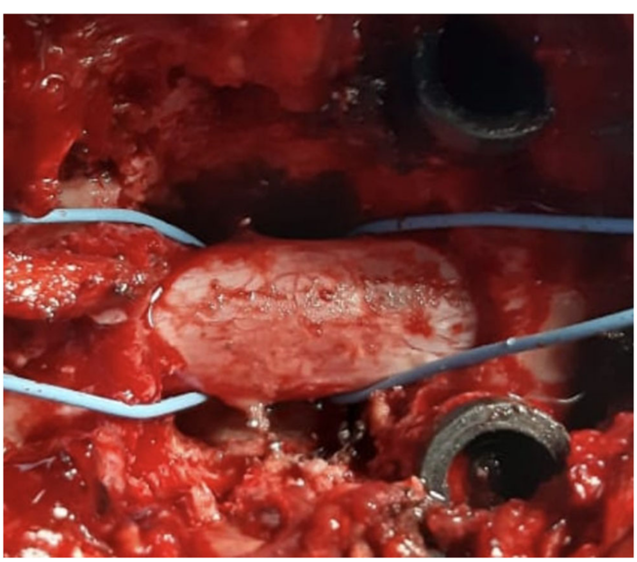

Fig. 6 Circumferential decompression (Patient 4)

Although safer than anterior procedures, costotransversectomy carries a different profile of risks compared to the transpedicular approach, especially for thoracic injuries removing the head of the rib. The most common respiratory complications included pneumothorax, pleural injury, lung contusion, atelectasis, and hemothorax. The rate of pneumothorax has been reported up to 25% in some series [35, 39, 40] although this could vary a lot depending on the experience of spine surgeons and the volume of procedures. In a series of 90 patients, Zhou et al. reported a 3.33% rate of pleural effusion and 1.11% rate of pneumothorax [41]. On the other hand the transpedicular approach carries an increased risk of incomplete decompression, because of inadequate visualization of the ventral epidural space, and also of spinal cord injury if excessive retraction is placed on dural sac. The resection of the head of the rib, added to pediculectomy, faces the challenge to achieve a better visual control of the ventral aspect of the spinal cord, avoiding its retraction, and to allow for a more comprehensive overview of the vertebral body decreasing the risk of a neurological damage.

This is why the endoscope could be a valuable aid in reducing the risks of these approaches. The use of the endoscope for spine spondilectomies has been described in previous reports [42–44]. In 2016, Archavlis et al. described the use of

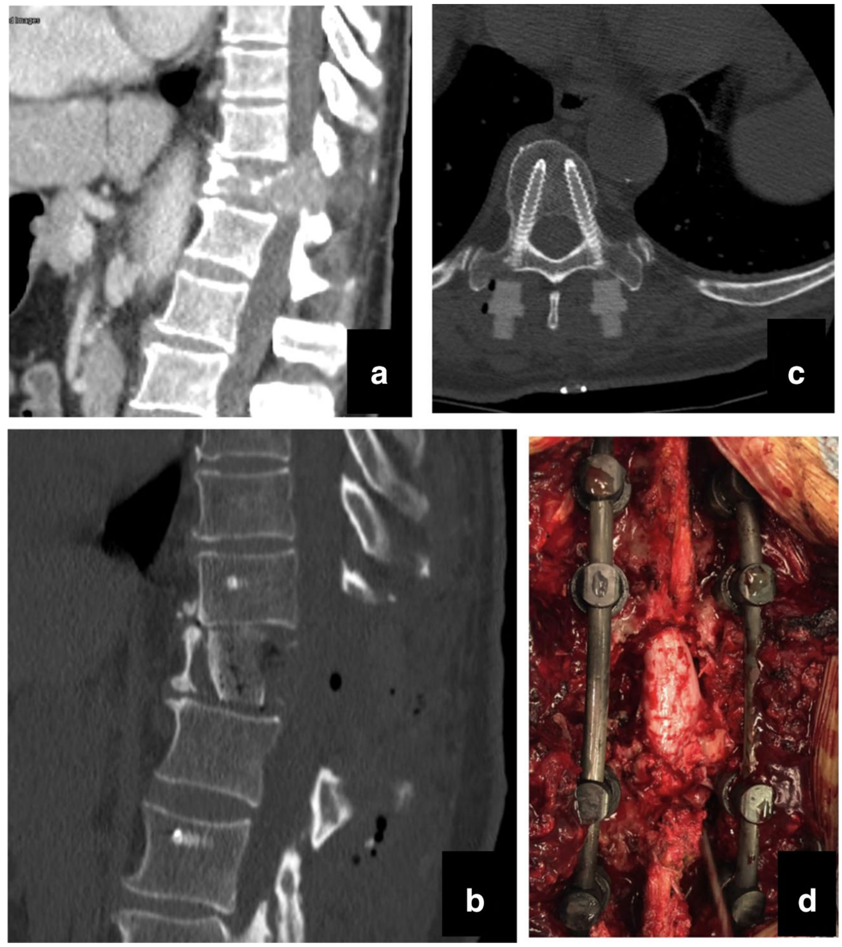

Fig. 7 Female, 70 years old (Patient 6), T11 colon cancer metastases (A). Stable paraparesis since 1 week. A total corpectomy was performed (B) with bone graft placement and fixation with carbon fiber pedicle screws (C,D)

the endoscope as a valid tool for transpedicular corpectomies. Their experience included seven cases, five of metastatic disease and two of burst fractures, all with a significant compression of the spinal cord. No neurological complications were recorded, and the endoscope was described as a significant help in identifying sources of active bleeding, residual tumor, bony removal, and in facilitating cage insertion [42].

The use of the 3D endoscope for a transpedicular approach, in this series, has allowed to achieve a proper circumferential decompression gaining a full vision of the ventral aspect of the spinal cord, avoiding even its gentle retraction, to dissect and cut the PLL and to extend the exeresis as deep as required without the need for a head rib removal with its related risks.

In this series, no major complications occurred. The mean duration of the procedures (260 min) together with the related amount of blood loss (580 ml) was acceptable. From a clinical point of view, five patients presented a neurological impairment before surgery, and all of them improved after the decompression at the last follow-up. Two of them were classified as grade D and improved to grade E after the procedure, while three grade C improved to grade D (one case) and grade E (two cases). IONM represented then a valid tool for the intraoperative safety of procedures [45].

NRS pain scores decreased significantly after surgery, with the average score value decreasing from a mean of 7.88 to 2.22. A proper separation surgery was achieved as confirmed by imaging, allowing for the best postsurgical treatment of the patients. Anterior reconstruction was possible when needed. No hardware failure has been recorded at last follow-up.

Limitations

This is, of course, a small case series with the aim of describing only the feasibility of this promising technique achieving separation surgery and its preliminary clinical results. The follow-up, although acceptable, is still too short to reach any definite conclusion about local control of the disease, concrete oncological advantages of this technique, and long-term complications such as hardware failure. Nevertheless, neurological improvement recorded months after surgery highlights the validity of decompression. Complications of the costotransversectomy, widely described in the literature, show a mildly different profile compared to the "open" transpedicular approach, but their rate maintains an acceptable level of safety. This paper shows no evidence of the superiority of the endoscopic approach in decreasing the approach-related complications compared to the costotransversectomy, as more cases and a long-term follow-up are needed to reach further conclusions. Finally, endoscopy could require a long learning curve and a dedicated setting in a center without previous experience.

Conclusion

According to preliminary results, the transpedicular 3D endoscope-assisted approach for thoracic corpectomies appeared to be a safe and effective technique to achieve proper circumferential decompression and valid separation surgery, potentially decreasing the need for costotransversectomy.

Compliance with ethical standards

Conflict of Interest The authors declare that they have no conflict of interest.

Informed consent The authors declare that an informed consent was obtained before surgery.

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