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TESI DI LAUREA

ULTRASOUND OSTEOTOMY: EVOLUTION OF SURGICAL TECHNIQUE IN ONCOLOGICAL SPINAL NEUROSURGERY

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ABSTRACT

Background. Spinal cord tumors (SCTs) can be classified into extradural-extramedullary tumors (60%), intradural-extramedullary tumors (30%, as neurinomas and meningiomas) and intradural-intramedullary tumors (10%, as astrocytomas and ependymomas). Surgical treatment is the gold standard, with the help of intraoperative neurophysiological monitoring (IONM). Histology sec. the WHO 2016 classification, region involved, degree of resection, age of patient are the factors that determine the prognosis. Evolution of spine surgery is relatively opaque, only in recent years the number of patients candidates for minimally invasive spine surgery and with high quality tools has expanded significantly. Sonopet® is safe for dura mater, nerves and vessels and consists of an handpiece and a console with three function, longitudinally vibration, irrigation and suction.

Aims. Our study takes under attention the development of surgical technique in spinal oncology over the years up to modern Neurosurgery. We describe how the Ultrasound Bone Aspirator device (Sonopet®) approach spinal tumors. Furthermore, we retrospectively review patients undergone surgery for spinal tumors at the Academic Neurosurgery, Department of Neuroscience DNS, University of Padua in recent years focusing on the relevance of this modern surgical nuance.

Materials and methods. We present a single-center series of patients, using ultrasound osteotome to perform laminotomy with poor morbidity. Sonopet® is a modern surgical tool, less invasive, manageable and allow to avoid incidental dural injury respect to laminectomy, minimizing blood losses and enhancing surgical quality. Spinal cord tumors from C2 to S1, histotypes of lesion adult and pediatrics population were inclusion criteria; cerebral lesions were excluded, as degenerative spinal disorders. We identified 39 patients, for a total of 42 procedures, collecting data on age, sex, operating time, instruments, blood loss, onset of symptoms, pre and post-operative neurological status at discharge and at 30 days, spinal MRI and CT scans with/without contrast, surgical techniques (laminotomies, laminectomies). We evaluated post-operative complications, neurological and neuroradiological follow up with spine RX at 30 days and with a 6 months spinal MRI. Follow up was with a range of 6-48 months with an average of 34 months.

Results. Population had a mean age of 46 years, radio M:F was 1.4:1, 23.8% aged between 50 – 60, 31% of procedures were strictly thoracic and 23.8% lumbar, 38.1% had an involvement of two vertebrae and 23.8% of one. Neurinoma and intramedullary expansive lesions (28.6% each) were the most frequent lesions in our series. Laminotomies performed were 14 (33.3%), Sonopet® was involved in 9 procedures (64.3%). Average time with Sonopet® was 278 min for laminotomy and

228 min for laminectomy. Blood losses collected showed lower Hb values in both surgical techniques, but more in laminectomies (110g/L vs 118g/L of laminotomies). Minor complications (minor sensitive impairment) occurred in 50% of procedures (n=21), resolved spontaneously in several weeks. In 8 cases with complication was used Sonopet® to perform surgical approach. In this series, zero in incidental dural injuries were encountered.

Conclusions. Further studies are suggested, use of Ultrasonic Bone Aspirator Sonopet® is useful in oncological spine procedures and should be encouraged.

RIASSUNTO

Background. I tumori spinali (SCT) possono essere classificati in: tumori extradurali-extramidollari (60%), tumori intradurali-extramidollari (30%, come neurinomi e meningiomi) e tumori intradurali-intramidollari (10%, come astrocitomi ed ependimomi). La chirurgia è il gold standard di trattamento, eseguita con l'aiuto del monitoraggio neurofisiologico intra operatorio. Istologia (secondo la classificazione WHO 2016), la regione coinvolta, grado di resezione, età del paziente sono i fattori che determinano la prognosi. L'evoluzione della chirurgia spinale è relativamente opaca, solo negli ultimi anni il numero di pazienti candidati alla chirurgia vertebrale mininvasiva e con strumenti di alta qualità è aumentato in modo significativo. Sonopet® è sicuro per la dura madre, nervi e vasi e consiste in un manipolo e in una console con tre funzioni distinte, vibrazione longitudinale, irrigazione e aspirazione.

Scopo dello studio. Il nostro studio prende in considerazione lo sviluppo della tecnica chirurgica in oncologia spinale nel corso degli anni fino alla moderna Neurochirurgia. Descriviamo come il dispositivo Aspiratore Osseo ad Ultrasuoni (Sonopet®) approccia i tumori spinali. Inoltre, esaminiamo retrospettivamente i pazienti sottoposti a intervento chirurgico per tumori spinali presso la Neurochirurgia Universitaria, Dipartimento di Neuroscienze DNS, presso l'Università di Padova negli ultimi anni, concentrandoci sulla rilevanza di questa moderna tecnica chirurgica.

Materiali e metodi. Presentiamo una serie monocentrica di pazienti in cui abbiamo usato l'osteotomo ad ultrasuoni per eseguire laminotomie con scarsa morbidità, in modo meno invasivo, maneggevole e accurato, evitando lesioni durali, minimizzando le perdite ematiche e migliorando la qualità dell'intervento. I tumori del midollo spinale da C2 a S1, gli istotipi della popolazione adulta e pediatrica sono criteri di inclusione; le lesioni cerebrali e disordini degenerativi spinali sono stati esclusi. Abbiamo identificato 39 pazienti, per un totale di 42 interventi, raccogliendo dati su età, sesso, tempi operatori, strumenti, perdite ematiche, insorgenza dei sintomi, status neurologico, RMN cerebrali e CT con e senza contrasto alla dimissione e a 30 giorni, tecniche chirurgiche (laminotomie, laminectomie). Abbiamo valutato le complicanze post-operatorie, il follow up neurologico e neuroradiologico tramite RX della colonna a 30 giorni e una RMN spinale a 6 mesi. Il follow-up riportava un range 6-48 mesi e media 34 mesi.

Risultati. La popolazione considerata aveva un' età media di 46 anni, il rapporto M:F era 1.4:1, il 23.8% di un' età compresa tra 50 e 60 anni, il 31% delle operazioni riguardava il distretto toracico e il 23.8% quello lombare, il 38.1% registrava il coinvolgimento di due vertebre e il 23.8% di una. I neurinomi e le lesioni espansive

intramidollari (ciascuno 28.6%) erano le diagnosi più frequenti. Le laminotomie eseguite sono state 14 (33.3%), coinvolgendo il Sonopet® in 9 interventi (64.3%). Il tempo medio con l'osteotomo ad ultrasuoni è stato di 278 minuti per le laminotomie e 228 min per le laminectomie. Le perdite ematiche hanno mostrato valori di Hb inferiori in entrambi gli approcci, ma più nelle laminectomie (110 g/L vs 118 g/L nelle laminotomie). Nel 50% delle procedure (n=21) si sono verificate delle complicanze minori (parestesie), che si sono risolte spontaneamente dopo alcune settimane. Solo in 8 casi dei 21 che hanno presentato complicanze era stato eseguito l'approccio chirurgico con Sonopet®. In questa popolazione non si sono riscontrate fistole liquorali.

Conclusioni. Ulteriori studi sono necessari, l'uso dell'aspiratore ad ultrasuoni Sonopet® è utile in interventi di chirurgia spinale e dovrebbe essere incoraggiato.

INTRODUCTION

1.1 ANATOMICAL NOTES

1.1.1 NEURAXIS AND SPINAL CORD

The nervous system is divided into two distinct components: the neuraxis and the neuraxial system. The former includes the nerve structures that are inside the skull and spine (encephalon in the cranial cavity and spinal cord in the vertebral canal), whereas the latter refers to the elements not contained within these bony structures. (1)

Spinal cord represents the most caudal part of Central Nervous System (CNS), with a mean length of 45 cm, mean diameter of 1 cm and it is contained in the vertebral canal. Its limits are the upper margin of the first cervical vertebra (Atlas - C1) and L1-2 vertebrae, although some differences may occur, based on age, sex and height. In these particular instances, the lower limit may be located farther cranially, at T12, or even further caudally, up to L3. At its conclusion the cord thins, generating the medullary cone and subsequently originates the filum terminalis, a fibrous chord that extends all the way to the 1st coccygeal vertebra. (2)

A distinctive feature of spinal cord is segmentation. Different portions of neuromeres can be identified: cranial segment (from C1 to C8), thoracic segment (from T1 to T12), lumbar segment (from L1 o L5), sacral segment (from S1 to S5) and coccygeal segment (from Co1 to Co3-4). (3)
CNS and, by extension, spinal cord, is encased by the meninges (dura mater, arachnoid and pia mater), three connective tissues, that are richly vascularized among them can be recognised three meningeal spaces, epidural (between periostium and dura), subdural (virtual, between dura and arachnoid) and subarachnoid (containing liquor). (4)

In contrast to encephalon, spinal cord externally contains white substance, which surrounds the grey substance (recognisable by its classic H-shape and formed by dorsal, lateral and ventral horn), from which originate the roots of spinal nerves. In this way, the ascending bundles, which transmit sensory information (i.e. pain, temperature, vibration and limb position) are able to reach encephalon, and from which subsequently depart the descending bundles, which control somatic and visceral motoneurons linked to skeletal muscles. (5) (6)

Spinal nerves consist of an anterior, thin, motor root (ventral root) and a posterior, thicker, sensitive root (dorsal root). Exceptionally C1 presents only the ventral root. Ventral root filaments arise from the anterolateral sulcus, whereas the dorsal root filaments penetrate from the posterior lateral sulcus. Next to the cord there is the spinal ganglion, a bulge formed by pseudo unipolar neurons that give birth to fibres that form the root itself. Inside the vertebral canal, the ventral and dorsal roots pass through the meninges, first of all through infraarachnoidal space, successively through the arachnoid and the dura, before joining at the level of the intervertebral foramen (IVF or conjugate foramen, after the apposition of the notches), in order to compose the spinal nerve. (7)

1.1.2 VASCULAR STRUCTURES

Spinal cord is supplied by segmental arteries that form an extramedullary and an intramedullary network. As reported (Fig. 1) (8), the extramedullary network consists of cervical, thoracic, lumbar and sacral arteries that flow equally and symmetrically alongside the respective spinal nerves, gaining entrance through the intervertebral foramina into the vertebral canal. The formation of longitudinal arterial trunks is the result of the merging of ascending and descending minor branches that sprout from each artery. The extramedullary network thus consists of anterior, left and right posterior an lateral spinal arteries. The anterior ones arise from the vertebral artery at the level of the inferior limit of the bulb and create the anterior spinal trunk, which descends down and ventrally, through in the anterior median fissure to C5. The two posterior ones originate from the vertebral artery as well. The lateral ones originate from the ascending cervical and vertebral, intercostal, lumbar, lateral sacral arteries and are composed by an anterior branch (which will form through anastomosis the anterior arterial tract) and posterior branch (which will form through anastomosis the posterolateral arterial tract). The aforementioned so generated arterial tracts form an anastomotic network known as subpial network, that penetrates into the spinal cord and forms the intramedullary network. This network is a terminal circulatory system comprised of an anterior and posterior median arteries, anterior and posterior radicular arteries and peripheral arteries. Specularly, median, radicular and peripheral intramedullary veins are formed, which flow into the perimedullary veins that form a median anterior, posterior, anterolateral and posterolateral venous tract and finally into efferent veins (lateral spinal and lateral emulgent, which project into the vertebral, intercostal, lumbar and lateral sacral veins). (9)

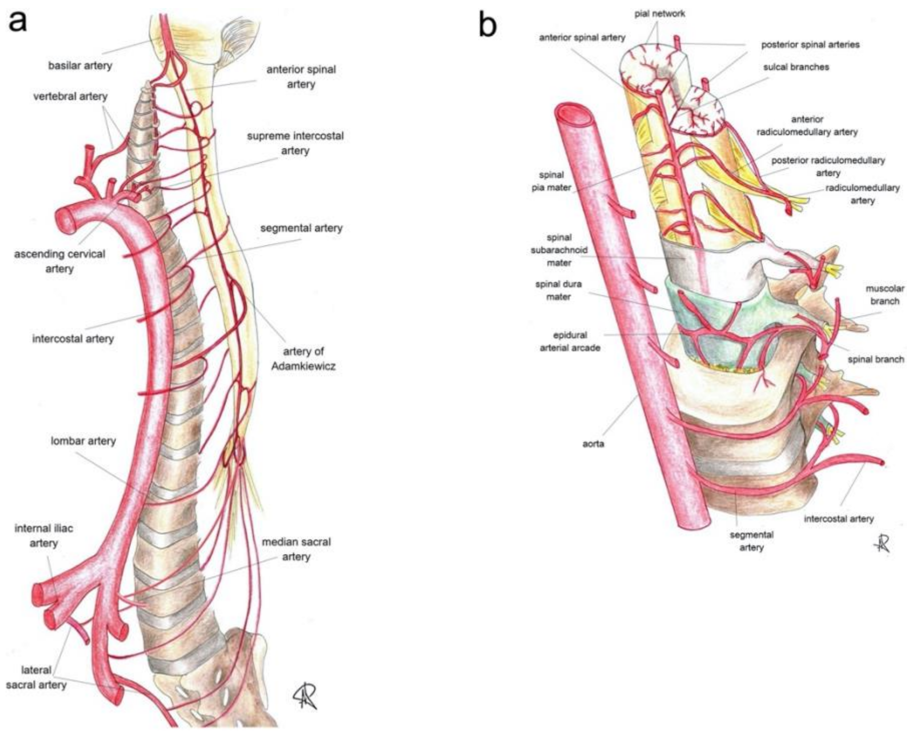

Fig. 1: arterial vascular structure of spinal cord (8)

1.2 SPINAL CORD TUMORS

1.2.1 DEFINITION

Based on their location, spinal cord tumors (SCTs) are classified into:

- Extradural-extramedullary tumors (ED-EMSCTs, 60% of total) (10)
- Intradural-extramedullary tumors (ID-EMSCTs, 30% of total), lesions growing within dura mater but outside the spinal cord parenchyma
  - Nerve sheath tumors (schwannomas, neurofibromas)
  - Meningiomas (10)
- Intradural-intramedullary tumors (ID-IMSCTs, 10% of total), formations growing between dura mater and spinal cord parenchyma, histologically devided into:
  - Astrocytomas
  - Ependymomas (10)

Extradural cancers are often metastatic, arising from sites distant from spinal cord (i.e. carcinomas located in breast, prostate, lung, kidney and thyroid (11)).

1.2.2 EPIDEMIOLOGY

ID-EM SCTs can press on the spinal cord parenchyma and nervous roots. Schwannomas have the tendency to develop into an hourglass form, to manifest firstly as radicular discomfort and secondly as motor impairments; they may typically be removed without sacrificing the nerve root, in contrast to neurofibromas, which involve and enlarge the nerve root (12). Meningiomas originate from arachnoid cap cells and are capable of calcification. They increase homogeneously, in contrast to nerve sheath tumors often have heterogeneous enhancement pattern on MRI (10).

ID-IM SCTs, which are relatively rare, are estimated to be 4-5% of all primary lesions in CNS. The majority (56%) are reported to be benign, while 31% are described as malignant neoformations. The most frequent are gliomas, especially ependymomas (45% of cases) and low-grade astrocytomas (35% cases). Increased cases of hemangioblastomas have been found in patients with VHL syndrome. As these tumors are so uncommon, there is only a little amount of data available, being able to describe effectively the population affected, the prevalence and the prognosis. (10)

Ependymoma: typically benign (WHO Grade II) tumors most likely located in the cervical segment. They are more prevalent in men and occur between the third and sixth decades. Ependymomas may be characterized histopathologically as myxopapillary, papillary, cellular, epithelial, or even mixed. Extremely uncommon are intramedullary ependymomas of WHO Grade III. (10) A longer survival rate has been demonstrated in association with the use of adjuvant radiation, although the function of chemotherapy has not been determined yet. En bloc resection are recommended whenever possible to limit spread. The recurrence rate is 40% with uncomplete resection and 20% when complete and effective. (10)

Astrocytoma: formations that affect cervical and cervico-thoracic areas, more common in children and young adults (1.5:1). WHO classifies astrocytoma into: pilocytic (grade 1), low grade (grade 2), anaplastic (grade 3) and glioblastoma multiforme (grade 4) (13). In adults WHO Grade III and IV lesions are more prevalent. Since a complete surgical resection is very unlikely to be successful, after 5 years the recurrence probability is 50%. They may extend over many segments, obstructing flow of cerebrospinal fluid (10). Astrocytomas are widespread, infiltrative, heterogeneously enhancing tumors that may include intratumoral cysts or necrosis. Due to the infiltrating nature of these tumors, a gross complete resection is not feasible. In contrast, ependymomas are often well confined and may include rostral and/or caudal cysts. (12)

Location	Entity		Region	Female/male ratio	Age	Distribution
ID-EM tumors (30%)*	Meningiomas		80% thoracic	1/5	5th–7th decade	50%**
	Nerve sheath tumors	Schwannomas Neurofibromas	Cervical = lumbar	1/1	4th–5th decade	30%**
	Filum terminale ependymomas		100% lumbar	1/2	3rd–5th decade	15%**
	Miscellaneous: dermoids, epidermoids, lipomas, teratomas, neuroenteric cysts					5%**
IMSCT (10%)*	Ependymomas		45% cervical	1/2	4th decade	55%***
	Astrocytomas		70% thoracic	2/3	3rd decade	40%***
	Miscellaneous: gangliogliomas, oligodendrogliomas, subependymomas, hemangioblastomas, neurocytomas, metastases					5%***

*Of all spinal tumors, **Among all ID-EM Tumors, ***Among all IMSCT

Table I: overview of ID SCTs (10)

1.2.3 ETIOLOGY

Etiology of STs is unascertained. Some genetic conditions correlate with the association with intradural tumors, such as neurofibromatosis 1 (NF1), neurofibromatosis 2 (NF2), Von-Hippel Lindau (VHL) syndrome. (14)

1.2.4 SYMPTOMS AND CLINICAL MANIFESTATIONS

Pain is commonly the first symptom to appear in extradural tumors. Neurologic impairments are caused by spinal cord injuries (i.e. spastic weakness, muscle weakness, sensory loss, incontinence, loss of bowel, bladder control in later stages). (14)

1.2.5 DIAGNOSIS

Although spine MRI is the gold standard for diagnosis intradural spinal malignancies (Table II) (10), other diagnostic procedures such as CT scans, angiography, CSF studies and neurophysiological examinations may be informative. CT scan is an alternative especially for detecting osseous spine, but MRI imaging has the capability to discern between other types of masses, such as abscesses and vascular malformations. Spinal x-rays gives information about destruction or distortion of vertebrae. Last but not least, a biopsy might clarify the diagnosis.

	T1	T2	Contrast enhancement	Special features
Intradural lesions				
Meningiomas	Hypo- or isointense	Hyperintense	++ Homogeneous	Calcifications, dural tail
Nerve sheath tumors	Hypo- or isointense	Hyperintense	++ Homogeneous	15% extradural growth
Dermoids	Hypo- or hyperintense	Hyperintense	– Thin enhancement around the periphery might be seen	Less likely to show diffusion restriction than epidermoids
Epidermoids	Isointense	Isointense or slightly hyperintense	– Thin enhancement around the periphery might be seen	Califications are rare White epidermoids occur due to hemmorhage or high protein content
Neuroenteric cysts	Variable depending on protein content	Variable depending on protein content	None	
Teratoma	Mixed signal from different components	Mixed signal from different components	Solid soft tissue components enhance	
Paraganglioma	Isointense	Hyperintense	++ Homogeneous	Hemorrhage is common (hemosiderin cap sign) Flow voids are common
Lipomas	Hyperintense	Hyperintense	– None	Hypointense in fat-supressed sequences
Leptomeningeal metastasis	Isointense	Hyperintense	++ Homogeneous	Sugar coating of spinal cord and nerve roots
Intramedullary lesions				
Ependymomas	Hypo- or isointense	Hyperintense	++ Homogeneous	Cystic in 50%, syrinx
Astrocytomas	Hypo- or isointense	Hyperintense	++ Heterogeneous	Cystic in 30%, leptomeningeal spread
Ganglioglioma	Hypo- and hyperintense (mixed)	Hyperintense	+ Heterogeneous	Calcification is common
Subependymo-ma	Hypo- or isointense	Hyperintense	None mild in some cases	Origin is the central canal Calcifications are possible
Hemangioblast-oma	Isointense (hypo- and hyperintensity possible)	Iso- or hyperintense	++ Homogeneous	Tumor cyst or syrinx is common
Lymphoma	Isointense	Hyperintense	++ Homogeneous	
Metastasis	Hypointense	Hyperintense	++ Homogeneous	Well-defined lesions, cysts are rare

Table II: MRI characteristics of ID SCTs (10)

1.2.6 THERAPY AND TREATMENT

A conservative therapy is not required, since the surgical treatment with excision is considered the gold standard. Worthily saying, deficits might rapidly reach an irreversible and permanent status.

If necessary, surgical treatment might be combined with radiation therapy. People with aggressive subtype of IMSCTs or EMSCTs may need radiation treatment and/or chemotherapy. (12)

Neuromonitoring, including somatosensory-evoked, motor-evoked and epidural D-wave motor-evoked potentials, guide surgeons during resection. The most prevalent surgical approaches are laminoplasty and laminectomy (with or without fusion). (12)

With regard to the surgical complications is better to emphasize the differences that may occur in this case between general complication after a surgical treatment and more specific neurological complications. The former include wound infection, hematoma of the operative cavity, deep venous thrombosis associated or not with pulmonary embolism (10), the latter give consideration to neurological impairments, leakage of cerebrospinal fluid and delayed post laminectomy kyphosis. (12)

1.2.7 PROGNOSIS

The histology, grade, region of spinal cord, degree of resection and age of patient are the factors that determine the prognosis. (10) Preoperative neurological state and treatment predict the long-term neurologic and functional prognosis after surgery. Rehabilitation plays a crucial role in outcomes of SCTs, focusing on a multidisciplinary team approach preventing complications, as well as a combination of medical, radiation and surgical oncology care. (10)

In IMSCTs additional prognostic variables, such as the longitudinal extension have been established as important as tumor site and histological diagnosis. There is correlation between extension farther than three levels of the vertebrae and a worse prognosis. Three or more laminectomies are reported to impact on the functional outcome. (10)

Talking about ependymomas, following the combination of surgery and subsequent radiation treatment, the majority of studies indicate overall survival between 50 and 100% at 5 and 10 years. (13)

For astrocytoma, the survival rate at 5 years reaches 60-90%. In contrast to the high grade astrocytoma, where the chances of survival over the long term are minimal, notwithstanding radiation treatment. The survival rate of primary malignant is 18.7% after 5 years with a median of 13 months, whereas the median survival for anaplastic is 17 months. (10)

1.3 OSTEOTOMIES THROUGHOUT HISTORY – AN HISTORICAL PERSPECTIVE

Evolution of spine surgery is relatively opaque, due to the fact that extremely few ancient world writings persists through ages and the lack of anatomical, pathological and etiological fundamentals. Surgery felt the effect of this miscomprehension and the development of spine surgery and neurosurgery did not occur until beginning of 1900.

1.3.1 ANCIENT AND MEDIEVAL WORLDS

1.3.1.1 EGYPTIAN AND BABYLONIAN PERIOD

Egyptian physicians were allowed to conduct dissections and discovered the role of immobilization. In the Edwin Smith papyrus, abscess treatment, surgical drainage, spine and skull damages are documented and enriched with specific diagnosis and prognosis. The papyrus is oriented in the neurosurgical field, reporting not only the morphological description of brain, skull, meninges and liquor, but also trying to give information about traumas and neurological sequelae.
Hammurabi’s Code contains laws that introduce the payment of surgical treatments based on the several economical efforts of the population, scalpel applications and patient death punishments. (15)

1.3.1.2 GREEK AND BYZANTINE PERIOD

1.3.1.2.1 HIPPOCRATES

Hippocrates the Koan (460-370 B. C.), pioneer of scientific medicine was the first to be concerned with anatomy and pathology of human spine.(16)
As a physician he deeply investigated the segmental structure of the column, its physiological curves, structure of vertebrae, tendons and vascularization. During his life he examined dislocations of vertebrae and fractures of the spinous processes.

He was used to split vertebrae into three different groups: the first one was the segment C1-C7, the second one was formed by the twelve thoracic vertebrae connected with the ribs and the last group included five vertebrae until the pelvis. Sacral and coccygeal segments, however, are only mentioned when he discusses physiological curves.

Investigating the fractures of the spinous processes, which usually heal rapidly and leave no complications, Hippocrates recommends to exercise forces with traction, ladder and the Hippocratic board. (16)

His writings reveal that external stabilization was more common and urinary retention issues pathognomonic of a severe spinal injury.

1.3.1.2.2 HEROPHILUS OF CHALCEDON

Educated by Praxagoras and Chrisippus, in contrast to his ancestors, performed more than one hundred dissections , reporting a lack of anatomical nomenclature. He also investigated nervous system, classifying them in motor or sensory. (15)

1.3.1.2.3 GALEN

Galen of Pergamum (129-200 A.C.) influenced the history of medicine for almost fourteen centuries, being the most renowned physician after Hippocrates. His production accounted 80% of ancient medical literature. (15) He described the emergence of nerves and established the neurological consequences of spinal damages at different levels. He had the chance to study anatomy in Alexandria of Egypt, the most famous center for anatomical dissections at that time, investigating wounds of gladiators, human corpses and vivisections or dissections on animals.

He claimed that column consisted of 24 vertebras, declaring the lateral position of the intervertebral foramina, where the nerves spread out. Discussing about the spinal marrow he reports that is a natural propagation of the brain, sharing the same texture.

He is the earliest to describe and illustrate the distribution of cranial and spinal nerves, cervical and brachial plexuses classification which will be lightly modified by Vesalius fourteen centuries later. He also investigates the clinical signs of spinal nerve injury and the sensory and motor malformations with great precision, as well as damages concerning upper section, like C1-2, or C3-4 ones. He documented paraplegia, retention or incontinence of faces and urine. (17)

1.3.1.2.4 PAUL OF AEGINETA

Byzantine physician Paul of Aegineta (625-690 A. C.) evaluated skull fractures, describing also instruments and procedures. He supported spine surgery in order to treat lamina fractures and suggested the possibility of a further cord compression. He strongly believed that decompression (technically a laminectomy) was the best treatment. (18)

1.3.1.3 ARABIC PERIOD AND PRESCHOLASTIC MEDICINE

Arabic schools preserved and traduced manuscripts from Greek and Roman physicians. Avicenna (980-1037 A. C.) traduced Galen and discussed about spinal stabilizations. (18)

1.3.1.4 MEDIEVAL PERIOD

Despite a robust educational system and dedication to human cure, this period was characterized by a dormient practical and surgical education. Roger of Salerno (ca. 1170), with his *Practica chirurgiae*, was the first to influence and discuss among surgical techniques, such as the checking of leakage of liquor during the Valsalva maneuver. His works included also nerves anastomosis, focusing on reposition. (18)

1.3.2 CONTEMPORARY SPINE SURGEONS

Laminectomies were the main surgery technique for resect spinal tumors. After this first experience in spinal oncology neurosurgeons focused their attention on minimally invasive spine surgery.

Paul of Aegina fulfilled laminectomies and established how to remove bone fragment. Because of poor prognosis, this surgery was not widely acknowledged by the medical community (15).

We have to wait until 1829, when Alban Gilpin Smith (1788-1869) expertly performs a laminectomy, splitting the lamina with a saw (16). The patient had suffered from a progressive paresis coming from an antecedent lumbar fracture and at the end of the procedure, his recovery was normal and regained sensibility. (17)

Spine surgery progressed slowly due to the prevalence of infections, at least until 1847, with the publication of Semmelweis and Lister on antisepsis. Twenty years later, antisepsis played a crucial role in operating protocol, increasing overall counting of surgical procedures. (17) Malgaigne (1806-1865) reintroduced the removing of spinous processes and trepanation, which lead to the first description of laminectomy, produced by Mac Ewen in 1886. (17)

1.3.3 VICTOR HORSLEY

In 1887, Sir Victor Alexander Haden Horsley conducted the first laminectomy with the aim to remove a spinal tumor and in 1890 he announced his results ahead of the British Medical Association.

He used to perform five operations in a day, a stunning record a surgical peaks. He worked on epilepsy, pituitary tumors and started stereotaxy. Despite being an extremely fast surgeon his operations were carefully planned in order to minimize damage and risky procedures under very difficult conditions. (19)

He was a talented surgeon who was reported to have brought the initial use of cranial bone wax for hemostasis, but recently was discovered that Henri Ferdinand Dolbeau, a French surgeon and professor, reported his use in 1850, almost fifty years before Sir Horsley, which proved the use of a new beewax called later bone wax on the 21st May 1892. Its components were beewax, almond oil and salicylic acid in 1%. Progressively Geary and Frantz use a polyethylene glycol composite and carbonwax which cause a significant less inflammation reaction. Today's bone wax is composite with 88% refined beeswax and 12% isopropyl palmitate. (20)

In recent years the number of patients candidates for minimally invasive spine surgery has expanded significantly and surgeons have become more skilled in the various approaches. Traditional open foraminotomies or laminectomies have been replaced with microendoscopic and microscopic approaches. By angling the endoscope or microscope is possible to perform minimally invasive laminectomies. It has been shown that patients who received these treatments have reach results that are comparable to those patients who undergo standard open approaches. (21)

Removal of especially ID-SCTs, has become more possible with the use of minimally invasive methods. Chiou in 1989 and Yasargil in 1991 removed a spinal tumor with an unilateral approach and other surgeons followed. (21)

Intraoperative ultrasonography, endoscopic techniques, tubular retractors, intraoperative neuromonitoring and fluorescent agents improved tumor localization, micro procedures and ability to safely remove the maximal tissue. (22)

Bonomo's hemilaminectomy and Lange's fixation technique upgrades the knowledge at the beginning of XX century. (23)

Cushing's establishment of Bovie's electrosurgical unit marked a significant step forward all types of surgical approaches, i.e. microscope, bipolar electrocoagulation, high-speed drills, ultrasonic aspirators and hooks, rods and screws that have been created to revolutionize the surgery of the spine. Next chapter will be based on nanotechnology and its millimetric structures. (24)

1.4 SONOPET: AN ULTRASONIC SURGICAL SYSTEM

The “Sonopet OMNI®, Ultrasonic Surgical System, model UST-2001”, a neurosurgical tool routinely used in the operating rooms of the “Azienda Ospedaliera di Padova”, is specifically and in-depthly described in this portion of the thesis. This instrument was developed by the “Synergetics™, Inc.”, based in Missouri and manufactured in Japan, more specifically in Kawasaki by the “Miwate Co., LTD”. (25)

Some of the benefits that should be mentioned are above all a more safety for the dura mater, nerves and vessels involved in the surgical procedures, a more effective speed compared with the other instruments, a more precise cut and control. These qualities can be verify in two different surgical procedures, in laminectomies and laminotomies. (26)

1.4.1 INTRODUCTION AND STANDARD EQUIPMENT

The device consists of different parts, a console, a mobile cart and one or more surgical handpieces. More specifically the handpieces are assembled by an handpiece, a disposable ultrasonic tip, a disposable irrigation sleeve, that covers most of the tip and a sterile tubing set.
Two distinct frequencies can be chosen, depending on the surgeon’s preferences and the surgical process itself. The handpieces can be ordered in a variety of combinations, but the most frequently used are the 25kHz handpiece and 34kHz handpiece. The console regulates the three functions of the handpiece, which are vibration, irrigation and suction. (25)

First of all, the vibration comes from the surgical tip, which is a tube made of titanium that is hollow. It vibrates longitudinally (sometimes longitudinally-torsionally) and preferentially fractures tissue or bone. This ultrasonic vibration is specific for tissues that have an high content of water and/or bones and consequently exhibits minimal or no impact on tissues that are rich of collagen. These features permit to preserve the structures that need to be preserved during surgery. (25)

Secondly, the irrigation during surgery on the surgical field is made possible by the release of a sterile irrigation fluid, which flow between the outer surface of the tip and the inner surface of the protective irrigation sleeve. The major purpose of this fluid is to suspend tissue fragments and maintain the tip's temperature at a cool interval.
Lastly, the suction is a vacuum process that permits to collect the fluid and the fragments of tissues from the surgical field. (25) (Fig. 2) (27)

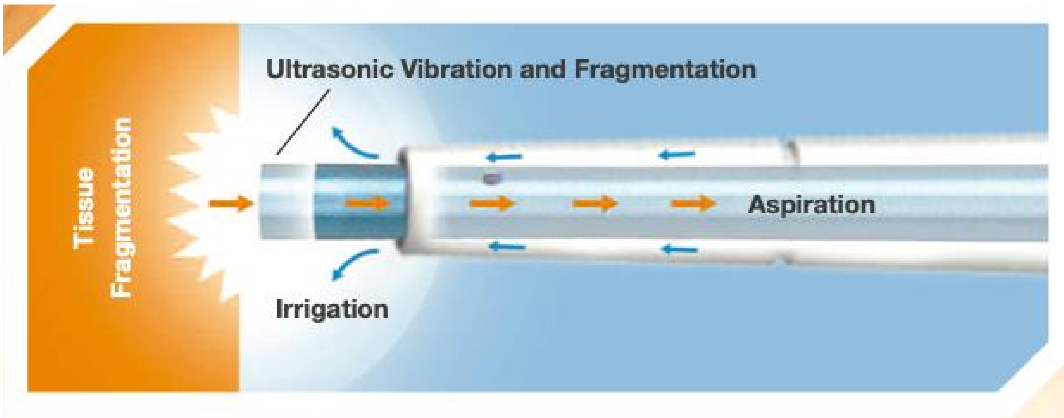

Fig 2: detail of component of Sonopet® (27)

1.4.2 SYSTEM SPECIFICATIONS

The transducer is a piezoelectric vibration system, the output power is continuous, the maximum output power amount of 100 watts, the system controls are full digital, the control panel is based on a display with touch panels. The frequencies used are 25kHz or 34kHz, the handpiece cooling is based on air cooled, the aspiration system is determined by a diaphragm pump, the aspiration pressure has a range from 0 to 500 mmHg.
The irrigation system consists of a roller pump and the irrigation flow rate can be between 3 and 40 ml/min. The handpiece sterilization can be conduced through ETO or steam autoclavable (132°C).
The system safety functions consists of an overload protection, a frequency shift protection and an output power malfunction indicator. The

electrical requirements are 11 VAC, 50-60Hz, 3A or 220 VAC, 50Hz, 2A, depending on the country.

The cart dimensions expressed in centimetres are 56.4 (W) x 62.5 (D) x 82.0 (H) and the console dimensions, always expressed in centimetres are 41 (W) x 40 (D) x 23.5 (H). The console has an approximal weight of 45 lbs. The safety standards are class 1, BF type and UL2601. (25)

1.4.3 THE SONOPET OMNI® CONSOLE AND HANDPIECE

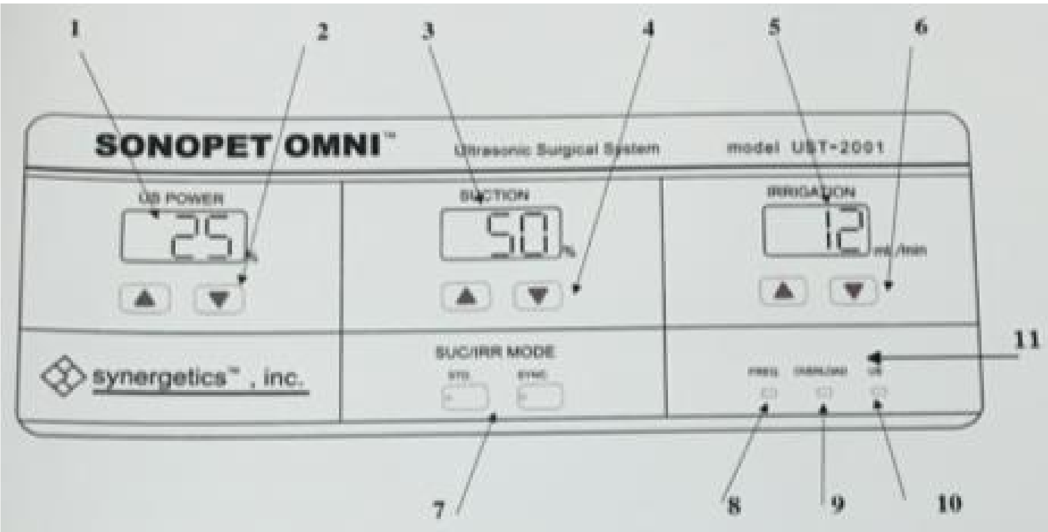

Fig. 3

1: Vibration indicator (illustrates the amplitude of tip movement)

2: Controls enable the increasing or decreasing of amplitude

3: Suction indicator (describes the aspiration level at the handpiece tip)

4: Controls enable the increasing or decreasing

5: Irrigation indicator (volume of fluid delivered expressed in ml/min)

6: Allows the control of irrigation (especially when footswitch is activated)

7: Suction/Irrigation Mode buttons (allow the surgeon to activate either the standard mode [STD., which lead to a minimal irrigation and suction during all time of using and maintain the tools clean] or the synchronized mode [SYNC., which works with irrigation and suction as well, but only when the footswitch is activated.])

8: Frequency Alarm Indicator (illuminates when the tip is damaged, incorrectly attached or due to excessive heat)

9: Overload Alarm Indicator (illuminates when the tip is under an excessive pressure or damaged)

10: Abnormal Oscillation Indicator (illuminates when there is a malfunction of the ultrasonic vibration circuit)

11: Irrigation/Pinch Valve alarm indicator (it is a safety feature) (25)

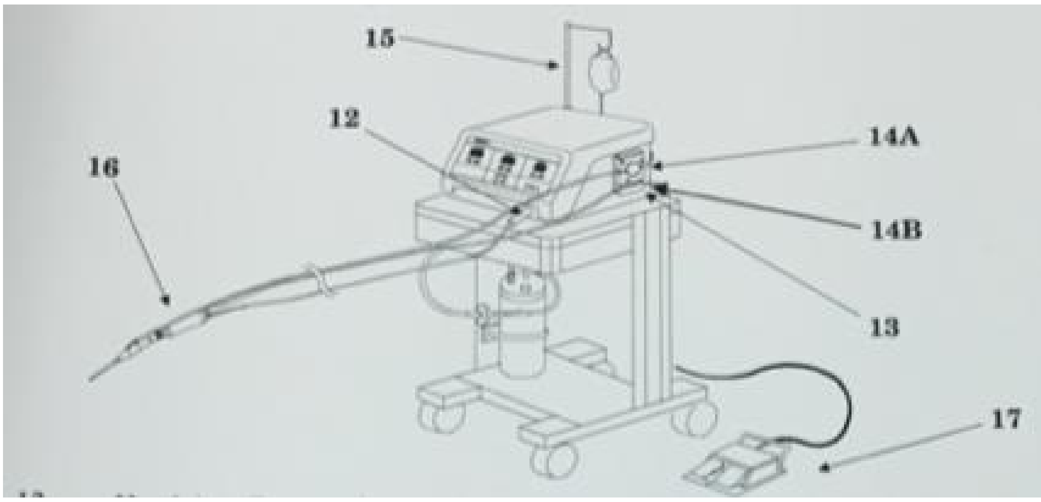

Fig. 4

12: handpiece receptacle

13: pinch valve (controls and stops the suction when irrigation is depressed)

14: irrigation pump and button that delivers irrigation fluid

15: IV pole (holds max 1L of saline solution)

16: surgical handpiece in complete assemblage

17: footswitch with two pedals (irrigation IRR and ultrasound US, which provides vibration, irrigation and suction) (25)

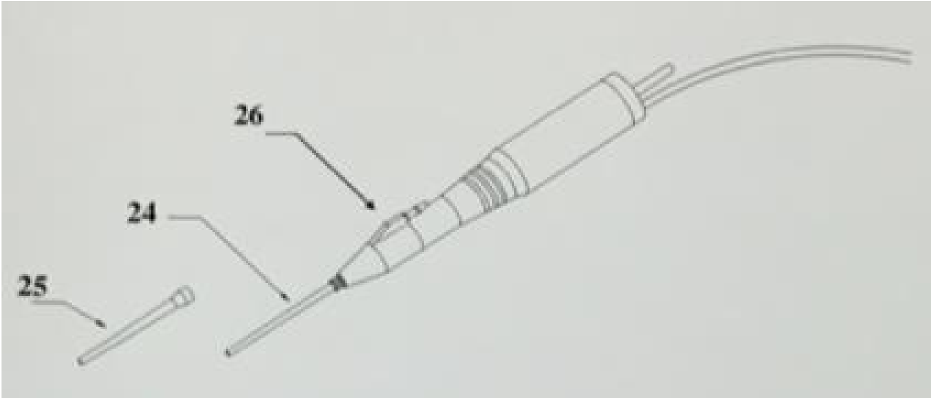

Fig. 5

24: Disposable ultrasonic tip

25: Disposable irrigation sleeve (the fluid flows coaxially between the tip and sleeve)

26: Handpiece tip cover (irrigation tubing connects to the irrigation port on the tip cover) (25)

AIM OF THE STUDY

The aim of our study is to take under attention the development of surgical technique in spinal oncology over the years up to modern Neurosurgery. We delineate the working of the Ultrasound Bone Aspirator device (Sonopet®) to approach spinal tumors.

Furthermore, we retrospectively review patients who underwent surgery for spinal tumors at the Academic Neurosurgery, Department of Neuroscience DNS, University of Padua in the last years with a special emphasis about the usefulness of this modern surgical nuance.

MATERIALS AND METHODS

3.1 DESCRIPTION OF THE EXPERIMENTAL DESIGN OF THE STUDY AND CONTEXT

We present a single-center series of patients undergone surgery for spinal tumors from June 2013 to August 2022 in Academic Neurosurgery of Padua.

In our study we emphasize the utility of ultrasound bone osteotome to perform laminotomy to obtain surgical access into spinal canal with poor morbidity and to reduce losses of blood, operative time and intraprocedural complications.

3.2 PATIENTS SELECTION AND INCLUSION/EXCLUSION CRITERIAL

Data were collected using our clinical software Galileo® according to inclusion criteria. The inclusion criteria were: spinal cord tumor that extended from the second cranial vertebra to approximately the first sacral vertebra, histotypes of lesions, adult and pediatrics population.

Indeed we identified 39 patients who undergo spinal surgery for intradural spinal tumors either intra and extra medullary.

We collected a total of 42 procedures.

All cerebral lesions were excluded, as degenerative spinal diseases.

3.3 ETHICAL ASPECTS

Each patient or parent if the case of an underage person signed an informed consent to treatment.

3.4 DATA COLLECTION

The data obtained were: age, sex, operating time, instruments used, blood loss, the onset of symptoms, pre and post-operative neurological status at discharge and 30 days after the operation, brain MRI and CT scans with/without contrast, surgical techniques (laminotomies, laminectomies) and use of IONM (Intraoperative Neuromonitoring).

3.5 DEFINITION OF OUTCOMES

In each patient were evaluated post-operative complications (pain, blood loss, motory or sensitive deficits, CSF fistula) occurred during recovery and at 30 days post discharge. Follow up included neurological evaluation with an average of 10 months and a neuroradiological follow up with a spine RX performed during recovery and post discharge (45 days of average) and with a spinal MRI with an average of 3.5 months post discharge with concomitant evaluation and a neurosurgical visit.

3.6 STATISTICAL EVALUATION

We reviewed retrospectively patients data, surgical parameters like operating times, blood losses and outcomes. We calculated mean and standard deviation.
As far as operative times are concerned, the interquartile ranges (IQR) were calculated.

3.7 SURGICAL TECHNIQUES

Ultrasonic osteotomy (UA) is a neurosurgical procedure that has gained worldwide popularity in spinal lesions. The most significant benefit with use of UA is to remove tumors in a less invasive manner, avoiding dural injury. The amount of operative time is shortened, blood losses are minimized if compared to high-speed drills, increasing the quality of the surgery. (25)

Among the benefits of this tool we emphasized a greater level of accuracy compared to laminectomy performed with Kerrison or high-speed drills, so leading to a reduction of blood loss and incidental durotomies. (28)

We emphasize that, respect to with high-speed drills, the Sonopet® is easier to handle because of its minimum weight, smooth motion in scratching and cutting bone tissue and preservation of dura and venous plexes, avoiding fistula CSF and hemorrhage. On the other side, although high-speed drills are able to cut bone quicker, they can scratch directly nerves and vessels and the procedure has to be interrupted for irrigate and aspirate surgical field. (29)

Since Sonopet® irrigation and ultrasound aspiration work simultaneously, thermal damage at soft tissues is avoided and according to Augustin et al. (28) also a lower incidence of cortical bone necrosis, which may develop when the temperatures reach and exceed 50°C is noticed.

Laminotomy is a uni or bilateral neurosurgical procedure, consisting in the temporary opening of vertebral canal removing a small portion of the lamina of a vertebral soma, so as to entry in spinal canal. Procedure is accomplished with reposition of the lamina with plates reconstituting the spinal anatomy at the end of surgical procedures. It is less invasive if compared to laminectomy, where we removed definitely vertebra bone. Leaving intact more portions of vertebra we obtaining faster recovery, less post-operative back pain and less spinal deformity at the distance.

Technical note: during the procedure the patient lies in prone position. A skin median incision is made in order to expose the vertebrae on the spinal level. Dissection of the paraspinous muscles from the spinous process and arch of the vertebra is required, whereas the bony structures and ligaments are kept intact. The ligaments which connects the upper

and lower vertebrae are removed or reshaped, with the aim to replace the small amount of bone loss. Is possible to accomplish a laminotomy on different and/or consequential levels; when performed, the procedure is known as a multilevel laminotomy.
Furthermore, after resection of tumor, reconstruction of bone anatomy is accomplished with titanium plates. (31)

RESULTS

4.1. CHARACTERISTICS OF THE POPULATION

Were collected between June 2013 and August 2022 a total of 39 patients in the Academic Neurosurgery, Department of Neuroscience DNS, University of Padua.

Mean age was 52.23 ± 26,85 years (SD), 23 were male patients and 16 females with ratio M:F 1,4:1 with age from 85 to 3 months (mean age 46.00 ± 26.62) at the time of surgery. Total neurosurgical procedures considered was 42, three patients had undergone previous spinal surgery.

4.1.1. AGE RANGES

AGE RANGES	FREQUENCY	PERCENTAGE
0-10	6	14.3%
10-20	6	14.3%
20-30	1	2.4%
30-40	2	4.8%
40-50	2	4.8%
50-60	10	23.8%
60-70	7	16.7%
70-80	5	11.9%
80-90	3	7.1%
	TOTAL: 42	TOTAL: 100%

Table III: age range, frequency and percentage of population

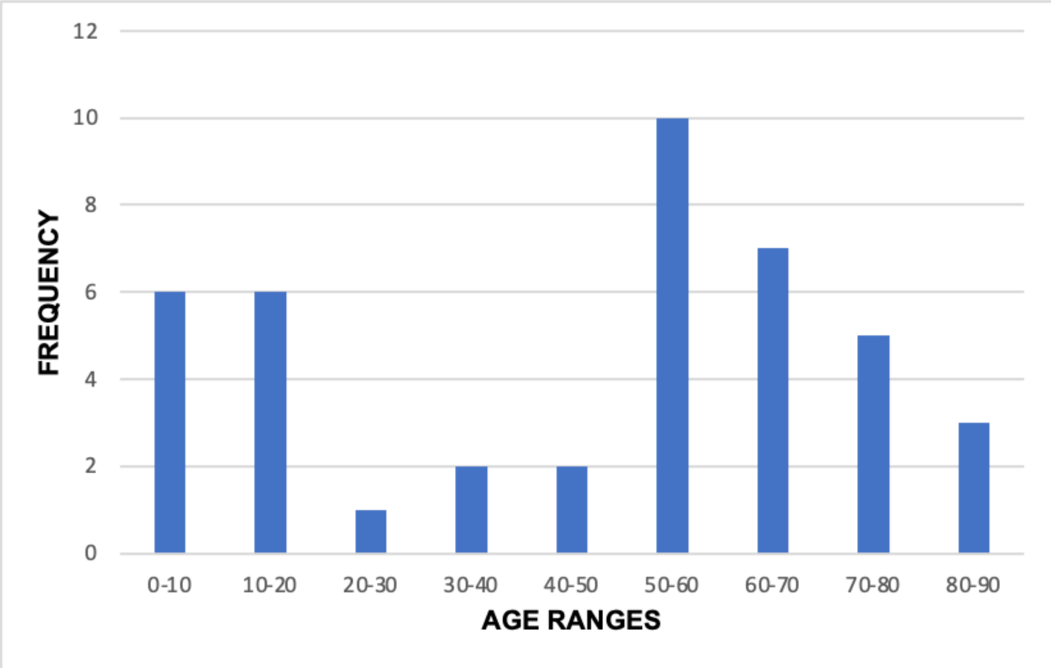

Table IV: histogram of age ranges and frequency

Notably, most patients (n=10, 23.8%) aged between 50 to 60 and 7 patients (n=7, 16.7%) aged between 60 to 70 years.

Furthermore, two age categories 0 to 10, 10 to 20 years were equally represented in number of 6 (n=6, 14.6% each).

This was followed by 5 cases in the 70-80 age range (n=5, 11.9%) and 3 patients aged ≥ 80 years (n=3, 7.1%). In conclusion, only 2 patients were respectively in the 30-40 and 40-50 years groups (n=2, 4.8%), while 1 patient in the 20-30 years age range (2.4%).

4.1.2. PROCEDURES' LOCATION

LOCATION	FREQUENCY	PERCENTAGE
CERVICAL	7	16.7%
CERVICO-THORACIC	4	9.5%
THORACIC	13	31.0%
THORACO-LUMBAR	4	9.5%
LUMBAR	10	23.8%
LUMBO-SACRAL	3	7.1%
SACRAL	1	2.4%
	TOTAL: 42	100%

Table V: location, frequency and percentage of procedures' locations

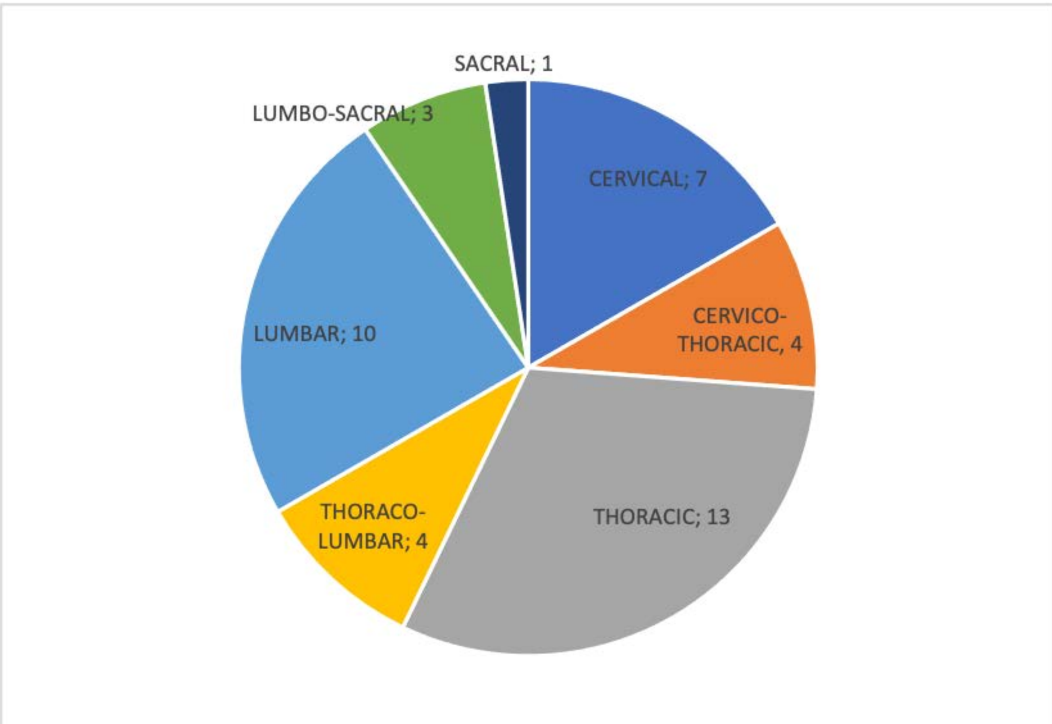

Table VI: pie chart of procedure's locations and frequency

After that, we chose to classify the operations based on their spinal location. Out of 42 surgeries, 13 were strictly thoracic (31.0%), 10 strictly lumbar (23.8%) and 7 cervical (16.7%). In addition, 4 procedures had access on either cervical-thoracic and thoraco-lumbar levels (9.5% each). In conclusion, 3 lumbo-sacral (7.1%) and 1 sacral (2.4%) approaches were accomplished.

4.1.3. NUMBER OF VERTEBRAE INVOLVED

NUMBER OF VERTEBRAE INVOLVED	FREQUENCY	PERCENTAGE
1	10	23.8%
2	16	38.1%
3	7	16.7%
4	2	4.8%
5	4	9.5%
6	2	4.8%
7	1	2.4%
	TOTAL: 42	TOTAL: 100%

Table VII: number of vertebrae involved, frequency and percentage

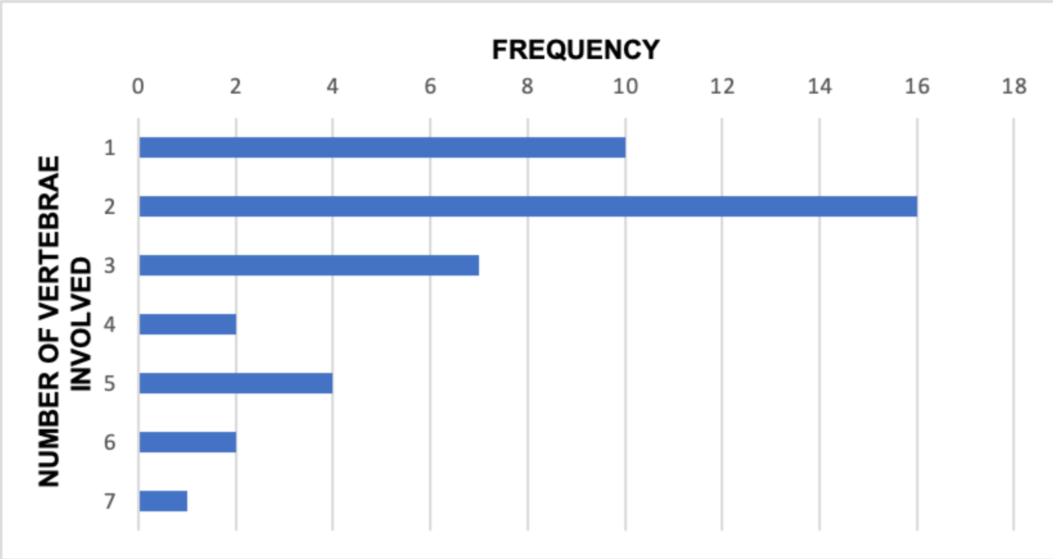

Table VIII: number of vertebrae involved, frequency

In terms of number of vertebrae involved, we reported an involvement of two vertebra in 16 patients (38.1%), followed by an involvement of one vertebra in 10, (23.8%). An approach on three vertebrae was performed 7 times (n=7, 16.7%), while a procedure on 5 vertebrae was indicated for four patients (n=4, 9.5%) and approach on 6 vertebrae were proposed for 2 cases each (n=2, 4.8% each). Lastly, one access was performed for 7 vertebrae procedure (n=1, 2.4%).

4.1.4. PRIMARY DIAGNOSIS

PRIMARY DIAGNOSIS	FREQUENCY	PERCENTAGE
MENINGIOMA	10	23.8%
NEURINOMA	12	28.6%
INTRAMEDULLARY EXPANSIVE LESION	12	28.6%
EXTRADURAL EXPANSIVE LESION	1	2.4%
OTHER	7	16.7%
	TOTAL: 42	100%

Table IX: primary diagnosis, frequency and percentage

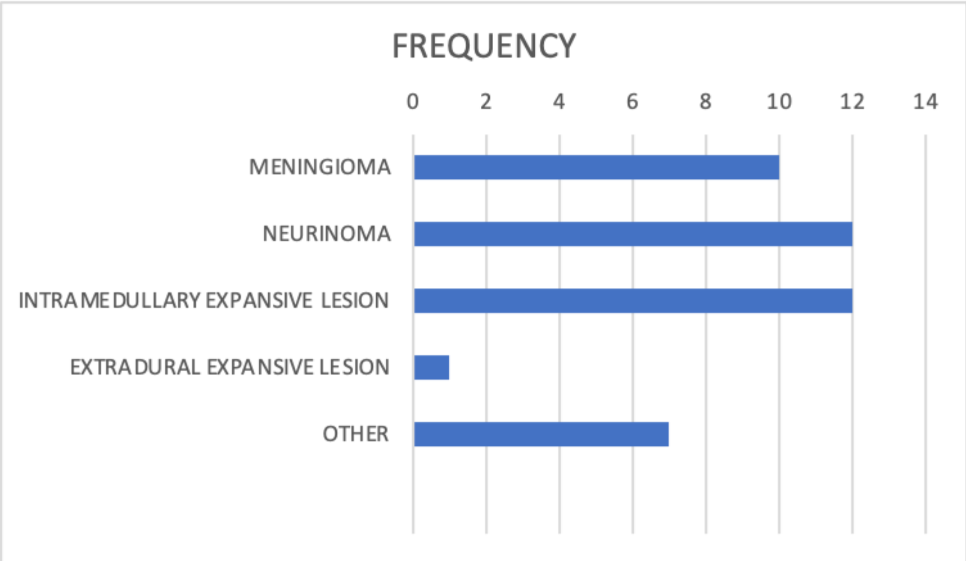

Table X: bar graphic of primary diagnosis and frequency

The most frequent histological diagnose was neurinoma (n=12, 28.6%), followed by meningioma (n=10, 23.8%) and intramedullary expansive lesions (n=12, 28.6%), including ependymomas (n=2, 4.8%).

Occasionally we reported extradural expansive lesion (n=1, 2.4%), lipoma (n=1, 2.4%), glioblastoma (n=1, 2.4%), germinoma (n=1, 2.4%), neuroblastoma (n=1, 2.4%) and pilocytic astrocytoma (n=1, 2.4%).

4.2. LAMINECTOMY VS LAMINOTOMY

4.2.1. SURGICAL PROCEDURES

SURGICAL PROCEDURE	FREQUENCY	PERCENTAGE
LAMINECTOMY + HEMILAMINECTOMY	28	66.7%
LAMINOTOMY	14	33.3%
	TOTAL: 42	TOTAL: 100%

Table XI: surgical procedure, frequency and percentage

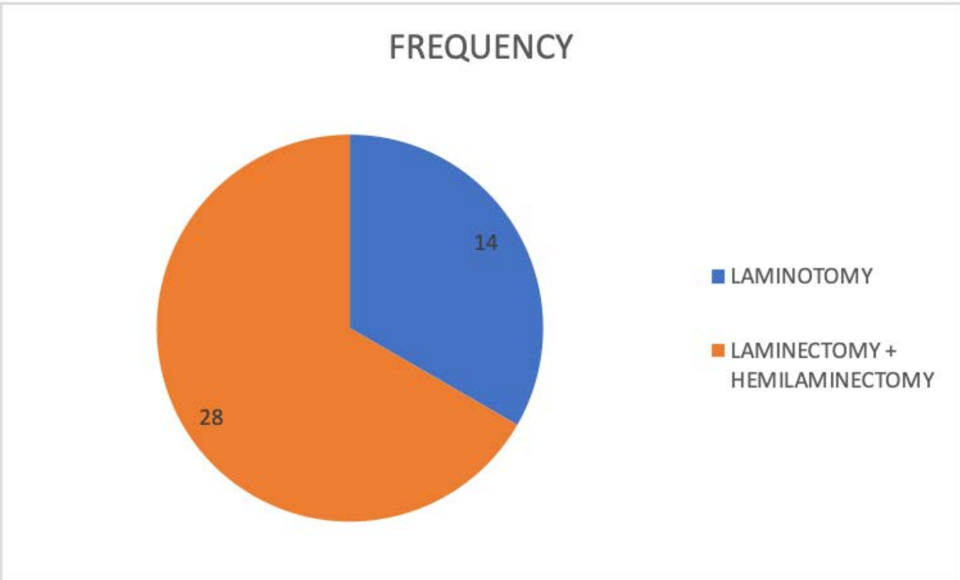

Table XII: pie chart of surgical procedure and frequency

Laminectomies and hemilaminectomies was performed in two half of surgeries (66.6%), laminotomy in a third (33.3%). To perform laminotomy was used Ultrasound bone scalpel Sonopet® in 9 procedures (64.3%).

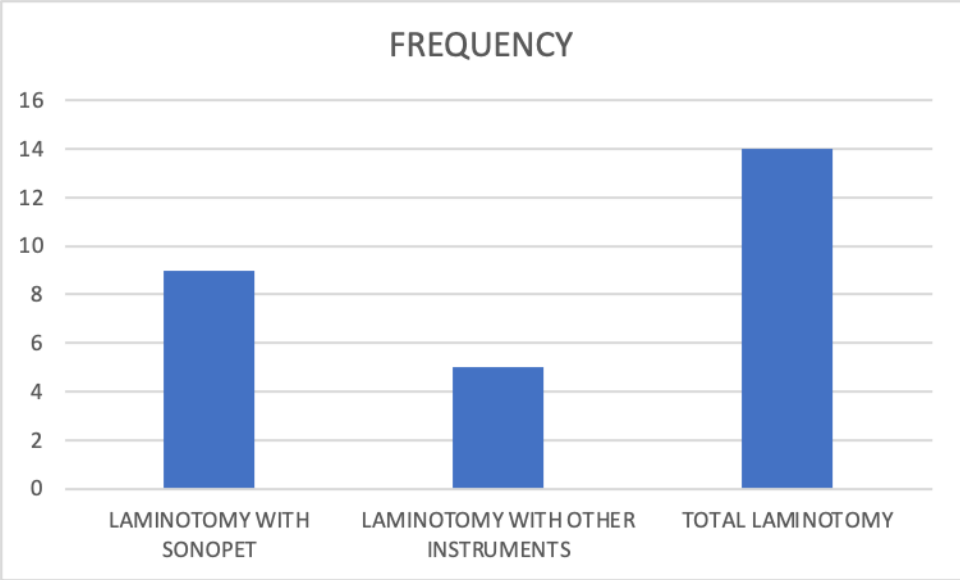

Table XIII: bar chart of laminotomy procedures and frequency

4.2.2. OPERATIVE TIMES

The mean length of total surgeries considered was 248 min ± 75.68 (SD). We were able to collect the operating times of 40 patients (95.2%), of whom 27 (67.5%) underwent laminectomy or hemilaminectomy and 13 (32.5%) laminotomy.

The mean length of laminectomies and hemilaminectomies studied was 231 min ± 76.94 (SD), while mean length laminotomies studied was 283 min ± 52.07 (SD).

CASE	LENGHT OF SURGERY (MIN)	TYPE OF SURGERY
1	300	LAMINECTOMY
	211	LAMINECTOMY
2	310	LAMINECTOMY
3	285	LAMINECTOMY
4	240	LAMINECTOMY
5	/	HEMILAMINECTOMY
6	195	LAMINECTOMY
7	165	LAMINECTOMY
8	270	LAMINOTOMY
9	165	LAMINECTOMY
10	270	LAMINECTOMY
11	180	LAMINECTOMY
12	270	LAMINECTOMY
13	120	LAMINECTOMY
14	330	LAMINECTOMY
15	345	LAMINECTOMY
	355	LAMINECTOMY
16	300	LAMINECTOMY
17	/	LAMINOTOMY
18	285	LAMINECTOMY
19	315	LAMINOTOMY
20	330	LAMINOTOMY
21	315	LAMINECTOMY
22	240	LAMINOTOMY
23	330	LAMINOTOMY
	329	LAMINECTOMY
24	210	LAMINECTOMY
25	150	LAMINECTOMY
26	265	LAMINOTOMY
27	80	HEMILAMINECTOMY
28	340	LAMINOTOMY

29	170	LAMINECTOMY
30	200	LAMINECTOMY
31	120	HEMILAMINECTOMY
32	380	LAMINOTOMY
33	150	HEMILAMINECTOMY
34	210	LAMINOTOMY
35	191	LAMINECTOMY
36	270	LAMINOTOMY
37	304	LAMINOTOMY
38	253	LAMINOTOMY
39	170	LAMINOTOMY

Table XIV: case number, length (min) and type of surgery

CASE	LENGTH OF LAMINECTOMIES + HEMILAMINECTOMIES (min)
1	300
	211
2	310
3	285
4	240
6	195
7	165
9	165
10	270
11	180
12	270
13	120
14	330
15	345
	355
16	300
18	285
21	315
23	329
24	210
25	150
27	80
29	170
30	200
31	120
33	150
35	191

Table XV: case number, length (min) of laminectomies and hemilaminectomies

CASE	LENGTH OF LAMINOTOMIES (min)
8	270
19	315
20	330
22	240
23	330
26	265
28	340
32	380
34	210
36	270
37	304
38	253
39	170

Table XVI: case number, length (min) of laminotomies

	LENGTH OF LAMINECTOMIES + HEMILAMINECTOMIES (min)	LENGTH OF LAMINOTOMIES (min)
MIN	80	170
1st QUARTILE	167.5	253
2nd QUARTILE (MEDIAN)	211	270
3rd QUARTILE	300	330
MAX	355	380

Table XVII: min, 1st quartile, 2nd quartile, 3rd quartile, max operative time of laminectomies and laminotomies

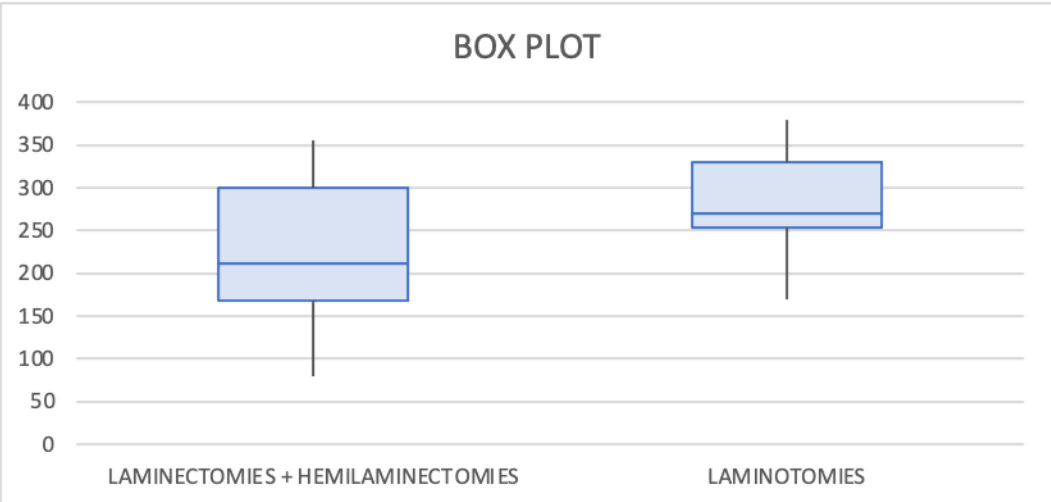

Table XVIII: box plot of min, 1st quartile, 2nd quartile, 3rd quartile, max operative time of laminectomies and laminotomies

	AVERAGE TIME WITH SONOPET (min)	AVERAGE TME WITH OTHER INSTRUMENT (min)
LAMINOTOMY	278	290
LAMINECTOMY	228	257

Table XIX: average operative time (min) of laminotomy and laminectomy with Sonopet® or other instrument

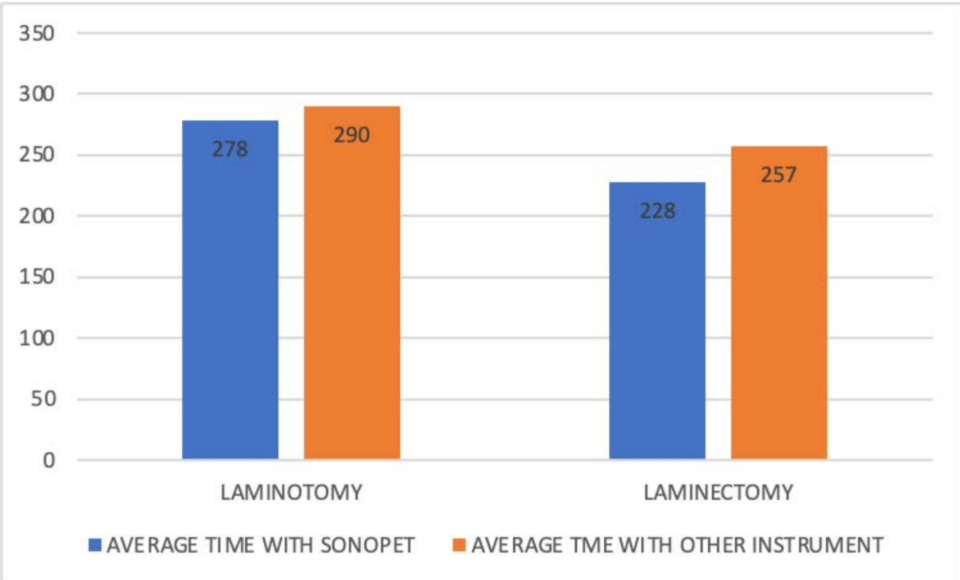

Table XX: bar chart of average operative time (min) of laminotomy and laminectomy with Sonopet® or other instrument

4.2.3. BLOOD LOSSES

With regard to the collection of blood loss during the procedure, we collected the exact values of a laminectomy (case 29, 50 mL) and an hemilaminectomy (case 31, 100 mL).

Further, we decided to collect the pre-operation hemoglobin values and/or the values obtained just after surgery and in the post-operative days, with a final average of 3 days.

	Hb VALUES (g/L) - LAMINOTOMIES		
CASE	**PRE-OPERATION**	**DAY OPERATION**	**POST-OPERATION**
8	120	/	106
19	131	/	116
20	158	141	137
22	127	/	116
23	138	122	115
26	135	/	125
28	108	/	106
32	152	/	114
34	144	/	129
36	152	/	138
37	141	121	119
38	154	116	136
39	113	89	100

Table XXI: case number, Hb values (g/L) of laminotomies

	Hb VALUES (g/L) – LAMINECTOMIES + HEMILAMINECTOMIES		
CASE	**PRE-OPERATION**	**DAY OPERATION**	**POST-OPERATION**
1	131	/	138
2	113	/	105
4	122	/	97
5	129	/	117
6	137	/	121
7	126	/	124
9	133	/	98
10	155	118	134
11	148	73	131
13	/	101	105
14	150	/	127
15	131	/	102
16	/	129	143
21	131	/	115
24	126	/	131
30	126	112	106
33	160	/	146
35	/	128	125

Table XXII: case number, Hb values (g/L) of laminectomies

	LAMINOTOMIES	LAMINECTOMIES + HEMILAMINECTOMIES
Hb pre-op (g/L)	136	135
Hb op (g/L)	118	110
Hb post-op (g/L)	120	120

Table XXIII: Hb values (g/L) of laminotomies and laminectomies

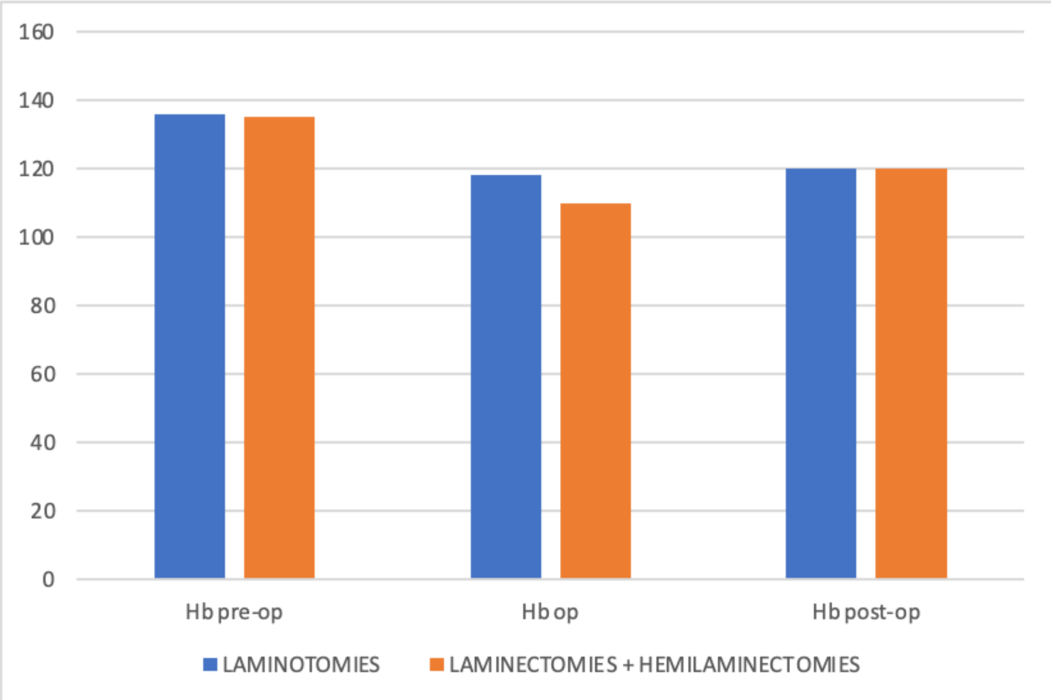

Table XXIV: bar chart of Hb values (g/L) of laminotomies and laminectomies

Before the laminotomy the average Hb value was 136 g/L, just after the operation 118 g/L and after an average time of 3 days it was 120 g/L. Regards laminectomies and hemilaminectomies, the mean value recorded preoperatively was 135 g/L, just after the operation 110 g/L and after a mean time of 3 days 120 g/L.

4.2.4. COMPLICATIONS

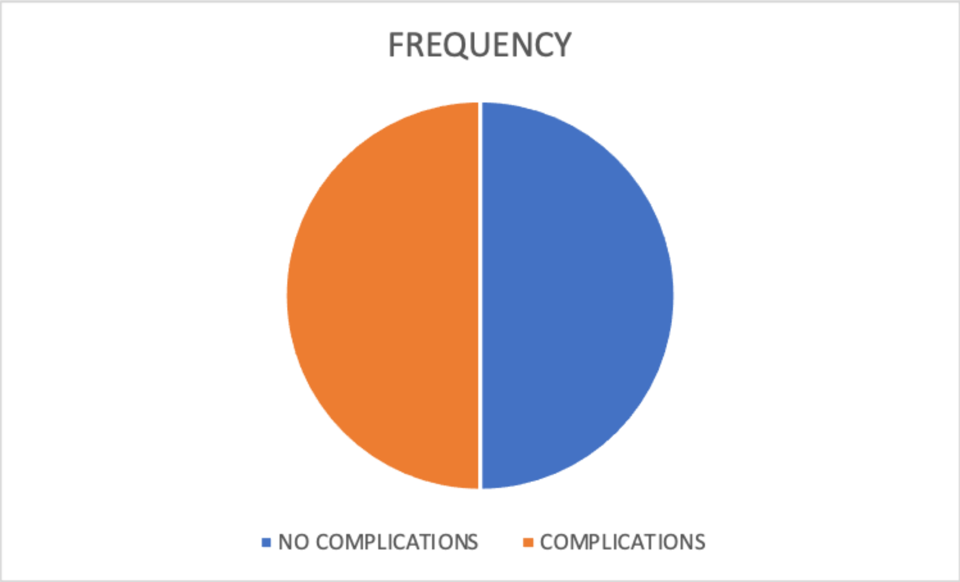

Table XXV: total complications

	LAMINOTOMIES	LAMINECTOMIES + HEMILAMINECTOMIES
COMPLICATIONS RESOLVED	8	13

Table XXVI: among complications (21), frequency of laminotomies and laminectomies

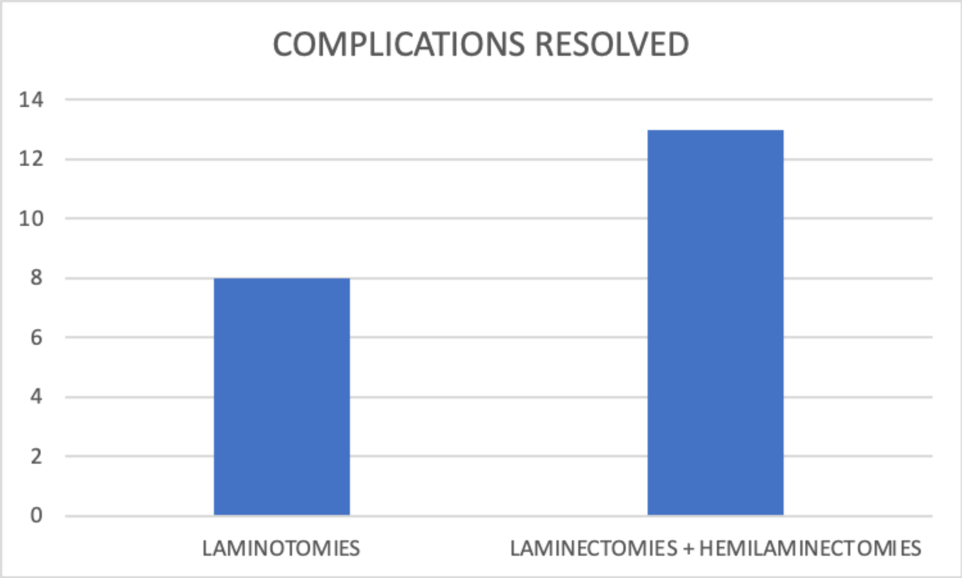

Table XXVII: bar chart, among complications (21), frequency of laminotomies and laminectomies

Regards peri and post-operative complications, in 21 cases (50%) the course of surgery was smooth and no complications occurred.

Post-operative complications were reported in 21 operations (50%). These were mainly sensitive deficits (i.e. paresthesias, hypoesthesias) and movement disorders (i.e. dystonias), walking deficits, urinary control deficits and mild pain, which, however, improved and regressed spontaneously in following weeks. Of these, more than half (n=13, 61.9%) were treated by laminectomy or hemilaminectomy and the other part (n=8, 38.1%) by laminotomy.

In one case of laminotomy, who undergone a laminotomy by piezoelectric, a blood transfusion was required.

In this series, a total of zero permanent dural injuries were encountered.

4.2.5. ILLUSTRATIVE IMAGES

Fig. 6: A pre-operative cervical MRI with contrast in sagittal plane show an intramedullary expansive lesion C4-5, treat with laminectomy

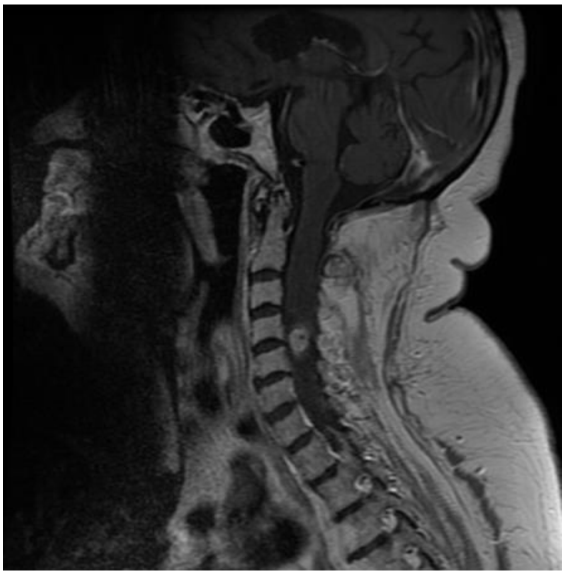

Fig. 7: Pre-operative cervical MRI with contrast in sagittal plan show an intramedullary expansive lesion C4-5. In this case was performed a laminectomy

Fig. 8: The same case of Fig 7; a post laminectomy cervical RX

Fig. 9: A cervical RX performed during follow-up post-laminectomy to treat an intradural meningioma C4-5. Evident an initial cervical spine misalignment

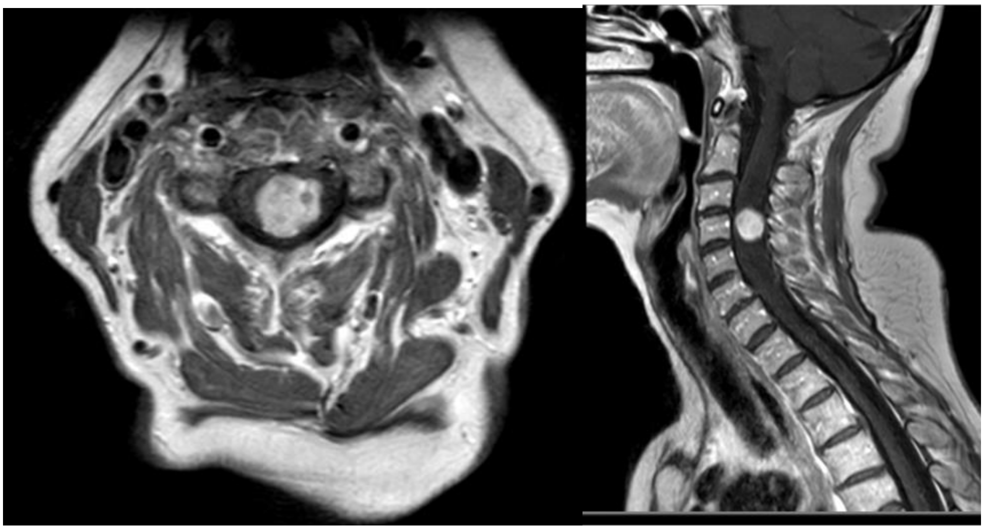

Fig. 10-11: Pre-operative spinal MRI with contrast in axial and sagittal plan that show a neurinoma C4-5. In this case was performed a laminotomy

Fig. 12: A post-operative cervical RX of a patient undergone to resection of neurinoma C3-6 with laminotomy and successive bone reconstruction with titanium plates

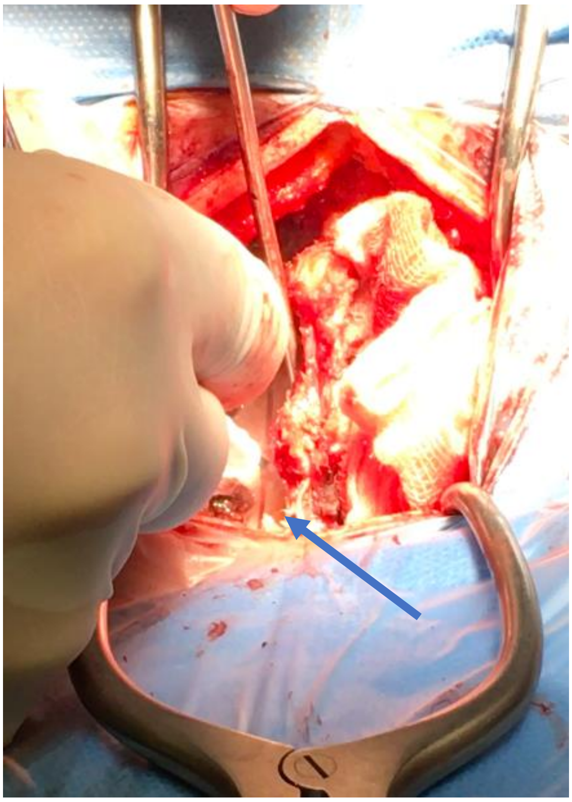

Fig 13: Intraoperative images: the Sonopet® handpiece and laminotomy is marked by the blue arrow

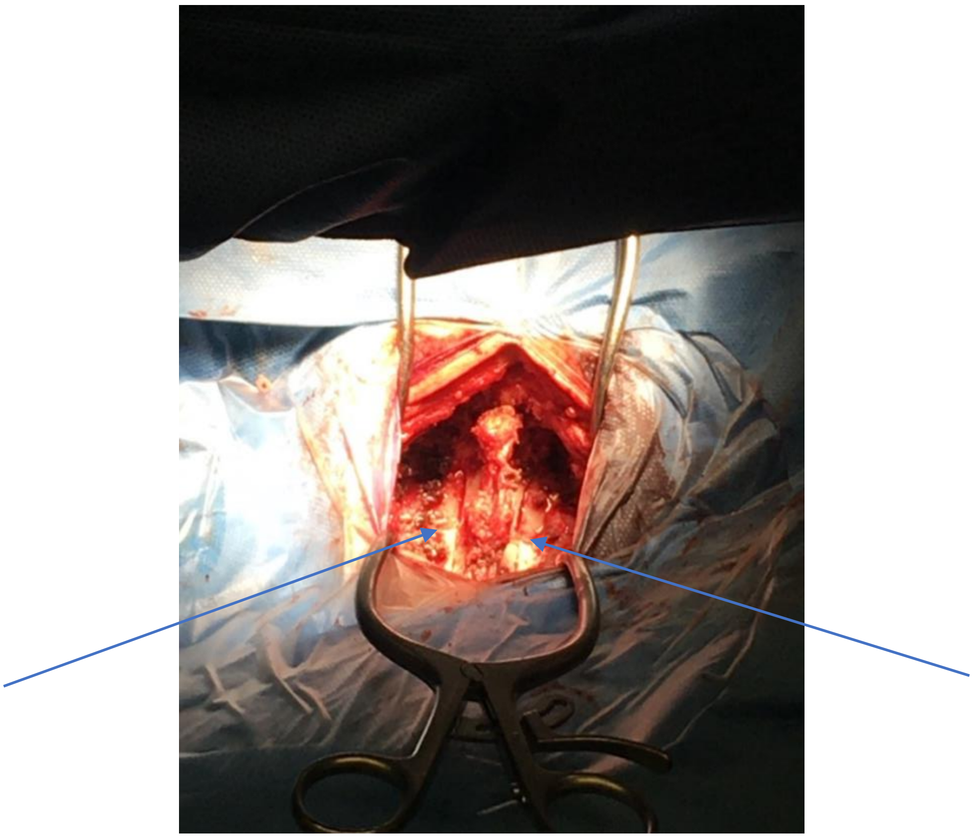

Fig 14: Intraoperative image: completed laminotomy

Fig 15: Titanium plates on vertebral lamina

Fig 16: Final reconstruction of spine anatomy with reposition of laminae of patients

DISCUSSION

Purpose of our study is to describe functional outcomes of patients undergone surgery for spinal tumors comparing laminotomy versus laminectomy technique and to observe whether or not they agree with the literature about this topic.

Baddour et al. (32) reported that use of ultrasound bone aspiration decreases blood loss and operative time per patient.
According to Velho et al. (33) experience on 96 patients this is a safe technique that may assist both cranial and spinal osteotomies. Such a tool permits precise bone cutting, minimum damage and avoids the danger of high-speed drills and saws.
Nakagawa et al. (29) show that high-speed drills are standard spinal instruments, but always linked to the possibility to damage dura, nerve roots and spinal cord, while Sonopet® plays a crucial role in upgrading spinal approaches and minimizing complications.

We collected 39 patients with mean age 46 years and 59% male. We included cases who undergone surgery between 3 months and 85 years old, with most frequency in range 50-60 years. Slightly less than three-quarters of patients were treated on strictly cervical, thoracic and lumbar level. 26 patients (61.9%) were operated either on one (23.8%) or two vertebrae (38.1%), with the primary diagnosis of neurinoma (28.6%), intramedullary expansive lesions (28.6%) and meningioma (23.8%).

5.1. INTERPRETATION OF THE RESULTS

Our study found that two-thirds of patients (n=28, 66.7%) had laminectomy or hemilaminectomy, which is consistent with other studies reported in the literature (31), but show an imbalance in the distribution of cases and following considerations.
In fact, laminotomies operations with this new type of instrument (Sonopet®) were acquired at a later date, and therefore are more recent. We are aware that this fact is a limitation for our study and further case recruitment is necessary.

From previous studies Velho et al. (33) and Ito et al. (31) reported that laminotomy has a minor mean length rather than laminectomies and hemilaminectomies, but in our study is shown that laminotomies had a mean length of 283 min, major when compared to the laminectomies, that had a length of 231 min.

Comparing the average operative times of laminotomies and laminectomies performed with and without Sonopet®, it is evident that Sonopet® reduces operating times in both surgical techniques, as reported in literature (34), although it remains a slightly shorter operating time in laminectomy (228 min and 278 min in laminotomy).
Although time difference is small, in laminotomies procedures advantages are innumerable, including better safety profile, minimized blood losses and fewer resolvable complications in the post-operative period.

With regard to blood loss, it can be seen that there are no significant differences in hemoglobin values measured pre and post-operatively at 3 days, whereas it can be seen that in immediate post-operative period hemoglobin levels were higher (118 g/L) in laminotomies.

At the same time, no serious peri and post-operative complications associated with ultrasonic device occurred in all the cases, which is in line with what is confirmed in the literature. All sensory deficits occurred in the immediate hospital stay resolved within a few weeks, which confirms the thesis that the use of ultrasonic osteotome produces less post-operative damage and a shorter hospital stay.

It is true that laminectomies have reported slightly shorter operating times, but they also registered complications in the post-operative period and all in all, the fact of a shorter operating time does not necessarily mean better post-operative outcomes, as has been reported in comparison with laminotomy surgeries.

Furthermore, in laminectomies, lamina is not repositioned at the end of the surgery and, as shown in Fig 6, the onset of minimal spinal instability and cervical lordosis is possible.

5.2. LIMITATIONS OF THE STUDY

The purpose of this study was to bring attention to a review of cases treated for spinal tumors with the use of Ultrasound Bone Aspirator device (Sonopet®).

This analysis was limited by the retrospective, observational design and the restricted number of patients enrolled, operations were performed by different surgeons, which may lead to variability and bias.

Even if bias, our study was comparable to other published series dedicated to similar cases. Laminotomy with ultrasound bone aspiration is promising.

Our results show that no dural injuries occurred, which is significant, due to the fact that for example in Xiaobang et al. (34) report, out of 128 patient retrospectively collected, 11 cases (8.6%) encountered dural injury. In addition, our review had no heat-related complications, also in agreement with what is reported in literature. (35) (31)

CONCLUSIONS

Further studies with a larger population of study are suggested, the use of Ultrasonic Bone Aspirator Sonopet® is a proven and useful technique in spine surgeries and should be encouraged.

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