CURRENT VIEW ON NEUROVASCULAR SURGERY COMPLICATIONS

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Asst. Prof. Dr. Emrullah Cem KESİLMEZ

LIVRE DE LYON
2022

Health Sciences

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Cover Design • Motion Graphics
Book Layout • Mirajul Kayal
First Published • October 2022, Lyon

ISBN: 978-2-38236-469-7

Publisher • Livre de Lyon
Address • 37 rue marietton, 69009, Lyon France
website • http://www.livredelyon.com
e-mail • livredelyon@gmail.com

LIVRE DE LYON

PREFACE

Today, along with technological developments, the fact that access to information is becoming easier plays a major role in the self-development of medical professionals. This change has led to considerable progress in the field of neurosurgery as well as in other fields of medical science. With the progress of neurosurgery in this way, advanced neurosurgical interventions can be performed in many centers. The increase in these neurosurgical interventions performed in many centers has led to an increase in the number of surgical complications. As in other surgical branches, it is very important to have sufficient information about the complications that may occur at least as much as the surgical procedure performed in neurosurgery. It is even more important to manage the surgical complication that occurs.

In this book, complications that may occur in some surgeries that are frequently performed in neurosurgery practice are explained and it is aimed to guide professionals working in the field of neurosurgery in their neurosurgical procedures.

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CONTENTS

CHAPTER I

PITUITARY ADENOMA SURGERY COMPLICATIONS

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1. Background

Pituitary adenomas are endocrine tumors which are originated from the proliferation of the cells belonging to the pituitary gland. They are usually benign tumors that can be symptomatic either according to the hormone production or mass effect. Studies have shown that while the total incidence of pituitary adenomas in the general population is 0.1%, it is between 0.039% and 0.074% per year. It has been determined that the prevalence varies between 0.076% and 0.116% with the increased use of MRI (Magnetic Resonance Imaging) (1). Although the complications are extremely rare and treatable, are still possible. Diabetes insipidus, anterior pituitary gland injury, intracranial hematoma, nasal septum perforation, carotid artery injury, sinusitis, central nervous system injury, cerebrospinal fluid (CSF) rhinorrhea, and meningitis are the main complications (2,3).

The foundations of pituitary surgery go back 100 years and various ways have been tried to reach the pituitary (4). The first attempt at the surgical resection of pituitary tumors was performed by Caton and Paul in 1893 using a temporal approach proposed by Sir Victor Horsley (5). After this intervention, Horsley operated on 10 pituitary tumors with a 20% mortality rate between 1904 and 1906 using the subfrontal and lateral middle fossa approach (6). In March 1907, Schloffer was able to surgically remove a pituitary tumor through a nasal transsphenoidal approach that was superior to transcranial surgery, identifying a less invasive route (7). Cushing performed the first transsphenoidal surgery on a patient with acromegaly in 1909, but insisted on the use of the intracranial route because of complications such as infection and CSF fistula (8). In contrast, Dott struggled to justify the transsphenoidal procedure again and had performed 80 consecutive operations without mortality until 1956 (9).

2. Transcranial vs Transsphenoidal Surgery

Although transsphenoidal endonasal procedures are the most preferred less invasive surgeries as the use of endoscopy increases day by day, transcranial surgery is still used in a minority of pituitary tumors. Among the situations in which transcranial surgery is preferred, those that show distant extension (suprasellar, parasellar or retrosellar/retroclival extension), tumors surrounding the vessels in the polygon of Willus or invading the optic chiasma or invading the cavernous sinus, doumble tumors, hard fibrotic tumors, presence of cerebral edema, presence of both carotids located very close (kissing carotids) and the presence of previous surgery or radiotherapy can be counted (10).

Surgery of pituitary tumors aims to reduce the tumor mass effect, eliminate the compression effect on the surrounding tissues, and perform as complete removal as possible. In the meantime, the normal function of the pituitary tissue should be preserved and if there is hormonal hypersecretion, it should be normalized.

3. Classification

According to the WHO classification change published in 2017, the term atypical adenoma, which is said to contain high proliferation and classified as a poor prognostic, has been completely removed due to a lack of conclusive evidence. Another change is the introduction of a more precise cell lineage-based classification of pituitary adenoma, which is defined based on lineage-specific transcription factors and hormones produced, with the increase in genetic cell lineage studies. Accordingly, tumors showing no staining for hormones or adenohypophyseal transcription factors were defined as empty cell adenomas (11). (Table 1)

Table 1: The 2017 WHO Classification Of Pituitary Adenoma

Adenoma type	Morphological variants	Pituitary hormones and other immunomarkers	Transcription factors and other cofactors
Somatotroph adenoma	Densely granulated somatotroph	GH±PRL±α-subunit LMWCK(perinuclear or diffuse)	PIT-1
	Sparsely granulated somatotroph	GH±PRL CK (dot-like; fibrous body)	PIT-1
	Mammosomatotroph	GH±PRL±α-subunit	PIT-1, ERa
	Mixed somatotroph-lactotroph	GH±PRL (in different cells) ±α-subunit	PIT-1, ERa
Lactotroph adenoma	Sparsely granulated lactotroph	PRL	PIT-1, ERa
	Densely granulated lactotroph	PRL	PIT-1, ERa
	Acidophil stem cell	PRL±GH, LMWCK (fibrous body)	PIT-1, ERa
Thyrotroph adenoma		b-TSH, α-subunit	PIT-1, GATA2
Corticotroph adenoma	Densely granulated corticotroph	ACTH, LMWCK (diffuse)	T-PIT
	Sparsely granulated corticotroph	ACTH, LMWCK (diffuse)	T-PIT
	Crooke's cell	ACTH, LMWCK (ring-like)	T-PIT
Gonadotroph adenoma		b-FSH, b-LH, α-subunit	SF-1, GATA2, ERa
Null cell adenoma		No markers	None
Plurihormonal adenoma	Plurihormonal PIT-1 positive	GH, PRL, b-TSH, ±α-subunit	PIT-1
	Adenoma with unusual immunohistochemical combination	Various	

4. Microscopic Transsphenoidal Surgery (mTSS) or Endoscopic Transsphenoidal Surgery (eTSS)

The pituitary region can be reached both by the transsphenoidal (microsurgical or Endoscope-assisted) approach and by the transcranial (pterional approach, anterior subfrontal approach) approach. Although Microscopic transsphenoidal surgery (mTSS) has been defined very well and its surgical results have been determined, new technology has been rapidly adopted in many skull base operations since the beginning of the twenty-first century, as a result of the introduction of the endoscope, with the development of technology. While a sublabial incision and removal of the nasal septum may be required during attempting mTSS, eTSS (endoscopic transsphenoidal surgery) can usually be performed with only a minor disruption of the nasal anatomy (12). Some studies have also shown that mTSS may be associated with a longer postoperative hospital stay compared to eTSS (13). In particular, the benefits of using an endoscope in the surgery of giant adenomas have been emphasized (14).

However, some studies have claimed that eTSS operations may take longer or result in higher CSF leakage complications than mTSS (15). Of course, it is thought that this situation may change over time with the increase in endoscope experience. Although there is no definite consensus in general, the benefit of the endoscope accompanying microsurgery is not to be underestimated.

5. Anatomy

While the pituitary gland forms the sellar region with the sella turcica, the tuberculum sella forms the anterior wall bone structure and the dorsum sella forms the posterior bone wall. The anterior and upper part of the tuberculum is the sulcus chiasmaticus. Both sides of the dorsum sellae form the posterior clinoids, and both sides of the sella turcica form the anterior clinoids. The floor of the pituitary fossa is the roof of the sphenoid sinus. The diaphragm sella incompletely covers the sella turcica as a roof. The adenohypophysis is separated from the optic chiasm by the diaphragm. The cavernous sinus is located in the parasellar region on both sides of the sellar region. Internal carotid artery, III, IV, V and VI. nerves are located within the cavernous sinus. In the suprasellar cistern, there are optic chiasm, third ventricle, hypothalamus and tuber cinereum (16).

5.1. Craniotomies and Surrounding Structures

To access the tumor, the approach with the least complications and the widest exposure should be preferred. The subfrontal approach is most commonly used and it provides easy access to the supra and parasellar areas. Among the craniotomies used are bifrontal interhemispheric, unilateral frontal, frontoorbital and frontotemporal craniotomies. There are neurovascular structures that can be damaged in almost all of the approaches. These include optic nerve and chiasm, pituitary stalk, vascular structures of the polygon of Willus (internal carotid artery, anterior cerebral artery, middle cerebral artery) and hypothalamic-hypophyseal perforations (17).

5.2. Optik Nerve

The position and placement of the optic nerve and chiasm with the tuberculum sella are important in terms of surgical planning and complications. Bergland et al. 3 localizations have been defined for the location of the optic chiasma. If the chiasm is located on the diaphragm sella, it is in normal localization. If the chiasm is located anteriorly, it is located just above the tuberculum sella and is called prefixed chiasma. If the chiasm is located posteriorly, it will be on the dorsum sella and is called the postfixed chiasma (18).

Since the optic nerve is located just above the pituitary gland, tumors growing in this location can cause compression on the optic nerve. When the chiasma is compressed, the visual field is more frequently affected, and apart from this, large tumors may cause complete deterioration of vision and even blindness. For this reason, visual field and visual acuity examination should be done before the operation decision. The most common finding after the visual examination is bitemporal hemianopsia due to the compression of the chiasma associated with the normal optic nerve location.

Traumatic optic neuropathy can be seen as a result of pituitary adenomas and surgeries. Although the treatment to be applied in this case is still controversial, surgical decompression of the optic nerve, which is under compression, should be provided first. In the treatment after surgery, conservative treatment or medical treatment can be applied (19).

Although the use of corticosteroids in medical peripheral and central nerve injuries is still controversial, it continues to be used because it is one of the rare medical treatment methods available for injuries. In some studies, corticosteroids are not effective on vision and there is no difference between the conservative approach and medical treatment. It has been mentioned that the results are similar in patients with initial visual impairment whether they use steroids or not (20).

6. Preoperative Planing and Avoiding Complications

All patients with pituitary tumors should undergo preoperative imaging with computed tomography and MRI, a full endocrine panel, and ophthalmologic evaluation in terms of both anatomical planning and postoperative follow-up. The endonasal transsphenoidal route, which is the most widely used route of pituitary adenoma, requires three basic steps, either endoscopically or microscopically.

6.1. Opening

Although there are different opinions about performing middle turbinectomy during endonasal intervention, it is aimed to damage less normal nasal tissue with the increase of minimally invasive surgery and the introduction of endoscopy into the field of use. In giant tumors, right middle turbinectomy can still be used because it provides a wide corridor and surgical area. In this first stage, it is recommended to remove a vascularized mucosal nasoseptal flap in giant adenomas that require a wide opening to enter the tumor, since it will reduce the risk of postoperative cerebrospinal fluid (CSF) leakage (14). Posterior septectomy may be required in some cases to enable the Binostril bimanual microsurgery technique. A wide sphenoidotomy is then followed, with bilateral opening of the lateral optico-carotid recesses and complete visualization from the tuberculum to the clival recess. The wider the anterior sphenoidotomy is, the more comfortable the manipulation of instruments in the sellar stage. If the tumor has spread significantly anteriorly and there is an extended approach, the tuberculum and planum sphenoidale should be opened. The base of the sellar bone opens to the medial wall of the cavernous sinus laterally, bilaterally to the superior intracavernous sinus, and inferiorly to the inferior intracavernous sinus. Neuronavigation or C-arm fluoroscopy can be used for site localization. In addition, Doppler ultrasonography can be used to identify the carotid arteries in the parasellar region on both sides and to guide the surgery.

6.2. Tumor Resection

When the excision of the tumor is started, the tumor is evacuated from the inside, piece by piece, using the microsurgery technique. Doppler ultrasonography can also be used to identify the vascular structures around the tumor from the inside. The tumor is then slowly dissected from the cavernous sinus. At this stage, leaking bleeding from the sinus may occur. Absorbable hemostats can be used for these leaking bleedings and the bleeding can be expected to decrease. During the operation after debulking, the pituitary gland should be differentiated by using a microscope or an endoscope. It is determined by the downward collapse of the diaphragmatic sella that the tumor has been adequately excised and gross total resection has been achieved. Methods such as increasing the intracranial pressure can facilitate the collapse of the diaphragm. Whether there is a residual tumor or not can be detected with the help of the endoscope (21). The risk of CSF leak complications may increase as a result of tumors invading the diaphragm sella or damage to the diaphragm after surgical manipulation.

6.3. Closure

There is still no consensus on how to repair the skull base. Many surgeons have published methods based on their experience and different methods are used in different centers. Multilayer closure methods can be used, especially in patients who are expected to have a CSF leak. For this, fat graft and facia lata graft can be used, and it may be necessary to use tissue adhesive on them. It is also recommended to add a facia lata graft to a small fat graft in cases where the diaphragm opens and there is CSF leakage. In some studies, it has been suggested that the interior of the sphenoid sinus is completely covered with large fat tissue and that dural mesh can be used on it (22).

Studies have been conducted on the nasoseptal flap used for repair after skull base surgery in patients with high-flow CSF leaks. It has been shown to be effective against CSF leak, but it can be seen as a gross surgery in terms of affecting the sense of smell and disrupting the nasal normal tissue (23). There are also studies that include the combined use of fat graft, fascia lata graft and nasoseptal flap, which states that multilayer closure is absolutely necessary to prevent CSF leak (24). Although it suggests that the application of intraoperative lumbar drainage during the perioperative period of transsphenoidal surgery for pituitary adenomas may reduce the risk of postoperative CSF leakage, stronger evidence is needed. Lumbar drainage can be used routinely or as needed (25).

7. Pituitary Axis Injury

Over 90% of the vasopressinergic neurons project from the supraoptic and paraventricular nuclei to terminate in the posterior pituitary. Changes in body water balance may occur as a result of injury to the pituitary stalk, posterior pituitary gland, or hypothalamus. These changes can be temporary only for mild reasons such as touching the stalk, or they can become permanent in serious structural disorders (Table 2). Diabetes insipidus (DI) may occur as a result of the decrease in antidiuretic hormone (ADH), which maintains the body water balance, or inappropriate ADH syndrome may occur as a result of excessive

ADH secretion (26, 27). The patient should be followed up in an intensive care unit where close follow-up can be made and monitored after the surgery. Fluid balance should be monitored every hour and urine-specific gravity measurements should be monitored every 4 or 6 hours. During this follow-up, the tests should be repeated when the urine output is more than 200-250 mL/hour. Likewise, serum and urine sodium and osmolality should be taken at least every 6-8 hours. Patients should be allowed to drink water freely and they should be able to drink water when thirsty. The diagnosis of DI is made as a result of high urine output (>250 mL/hour in 1 to 2 hours) and decreased urine density (<1.005). After the development of DI, both oral and IV fluid replacement is continued for the patient. If the amount of sodium begins to increase after fluid supplementation and cannot be compensated, treatment is necessary. In this case, it is necessary to start desmopressin therapy.

Desmopressin can be given as orally divided doses starting from 0.1 mg up to 0.8 mg daily. (MINIRIN® Melt 120 microgram tablet. Can be increased up to 720 mg. Can be used in divided doses) Nasal spray can be given as (MINIRIN® 0.1 mg/ml nasal spray), 10-20 micrograms can be used 1-2 times a day. Apart from this, clofibrate, chlorpropamide, and hydrochlorothiazide can also be used in cases where there is no ADH total loss.

Table 2: Three models of Diabetes Insipidus

Transient DI:	Abnormal urine output (UO) and polydipsia that typically normalizes ≈12–36 hours after surgery
Prolonged DI:	It can be for a long time or even permanent. Some may return to normal up to 1 year later.
Three-phase response:	1: ADH stays low for 4-5 days →DI 2: ADH is released and released for 4-5 days. This causes a temporary normalization and even water retention from excess ADH. 3: Decreased or absent (transient or prolonged) ADH secretion

(Handbook of neurosurgery, 8th edition, by Mark S. Greenberg, New York, Stuttgart, Delhi, Rio de Janeiro, Thieme, 1661 pp., 2016: 747-755 ISBN 978-1-62623-241-9)

Table 3: Perioperative Complications

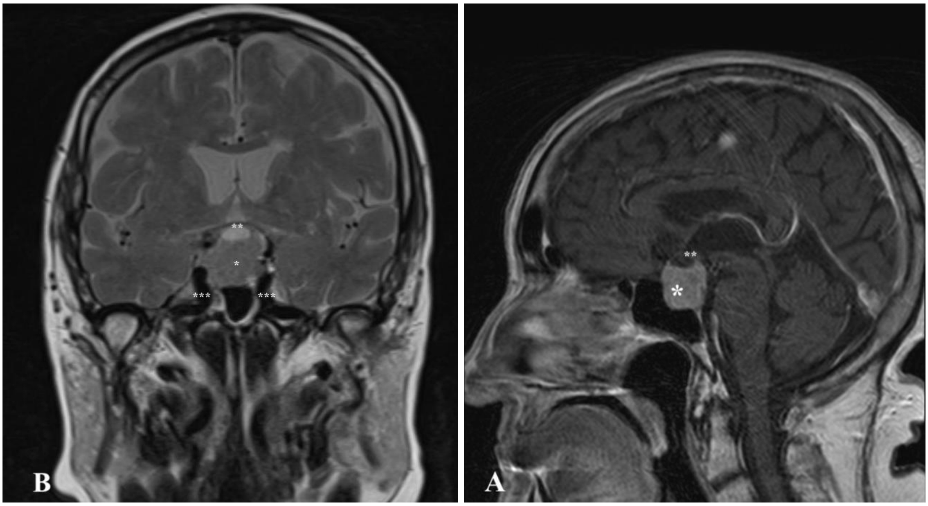
Hormonal imbalance	Changes in ADH
	Hypocortisolism
	Hypothyroidism
	Adrenal insufficiency
	Hypogonadotropic hypogonadism
Secondary empty sella syndrome	
Hydrocephalus	Traction in the connected 3rd ventricle
	Cerebral edema due to vasopressin release from manipulation of the pituitary and/or stalk
	Tumor edema
Infection: Abscess or meningitis	
CSF leak	
Carotid artery rupture	
Damage to the structures inside the cavernous sinus	
Nasal septal perforation	

(Handbook of neurosurgery, 8th edition, by Mark S. Greenberg, New York, Stuttgart, Delhi, Rio de Janeiro, Thieme, 1661 pp., 2016: 747-755 ISBN 978-1-62623-241-9)

8. Carotid Artery Injury

It is an excessive arterial bleeding that can be a serious disaster. Packing with fat graft or fascia lata graft can be done with compression. The operation should be immediately terminated and a STAT post-op arteriogram should be performed. Detected pseudoaneurysm or injury site must be treated as it can cause serious fatal bleeding. Endovascular treatment or clipping can be done with open surgery.

Figure 1: Contrast-enhanced sections of cranial MRI the pituitary adenoma. A. Sagittal section B. Coronal section. *Pituitary adenoma **Optic chiasma



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CHAPTER II

SURGICAL COMPLICATIONS OF SHUNT PROCEDURES FOR HYDROCEPHALUS

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1. Introduction

Selective evacuation of cerebrospinal fluid (CSF) by one of the shunt procedures is a treatment method used in multiple diseases. These diseases are hydrocephalus, intracranial hypertension, CSF leakage, and CSF fistulas. This article aims to give information about the complications of shunt procedures for hydrocephalus.

2. Hydrocephalus

Hydrocephalus is the presence of ventriculomegaly with an increase in intracranial pressure. Hydrocephalus occurs with three mechanisms: excessive cerebrospinal fluid production, malabsorption, or obstruction in the circulatory pathways. Hydrocephalus does not refer to disease alone but as a fatal neurological condition. So the primary treatment should be directed to the etiology of hydrocephalus. However, in the presence of hydrocephalus, in cases where the primary etiology cannot be treated or treatment cannot prevent hydrocephalus, evacuation of cerebrospinal fluid is required to reduce intracranial pressure.

3. Shunt procedures

Some surgical shunt procedures are performed to drain the cerebrospinal fluid. These shunt procedures can be classified as intra-thecal or extra-thecal shunt procedures.

3.1. Intra-thecal shunt procedures

The intra-thecal shunt procedure refers to the redirection of cerebrospinal fluid to another compartment by an endoscopic method if there is an obstruction in the circulatory pathways of the cerebrospinal fluid and there is no absorption defect.

3.1.1. Endoscopic 3rd Ventriculostomy

In the endoscopic third ventriculostomy (ETV), a defect is created from the base of the third ventricle to the prepontine cisterna with the help of an endoscope. In this way, the cerebrospinal fluid is directed to the subarachnoid space in another compartment. The indications for the application of ETV are limited, and there is a possibility of failure. ETV is useless in communicating hydrocephalus. It is indicated only in selected cases of obstructive hydrocephalus. These cases are usually aqueductal stenosis, pineal masses, and tectal lesions. When intra-thecal shunt procedures are compared with extra-thecal shunt procedures, it is reported that one is not superior to the other. (1) When the ETV application fails, the ETV process is not repeated, and extra-thecal shunt procedures are performed. (2) The need for extra-thecal shunts after ETV application in aqueductal stenosis has been reported as 20%. (3) The ETV success rate in infants younger than three months of age is reported to be less than 25%. (4, 5)

3.2. Extra-thecal shunt procedures

Extra-thecal shunt procedures refer to the evacuation cerebrospinal fluid to another body cavity with a permanent shunt material. They are often preferred in post-hemorrhagic or post-infectious hydrocephalus. In addition, this procedure is also preferred in cases where the ETV application is unsuccessful or in patients who have previously undergone extra-thecal shunt procedures. The shunt material used in these procedures consists of 3 units. These are; a ventricular catheter, shunt valve, and distal catheter. The ventricular catheter is often inserted into the lateral ventricle from the right frontal or parieto-occipital region. Then the ventricular catheter is connected with a valve under the skin. Although the pressure settings of the valves vary, there are also programmable ones. At the same time, an anti-siphon device is added to the valve against the siphoning effect that may occur due to the patient's postural change. Then, the procedure is completed by connecting the shunt system with a distal catheter placed according to the selected shunt procedure. Thus, the cerebrospinal fluid begins to be permanently drained. There are alternative ways to each other for localizations in which the cerebrospinal fluid will be evacuated. Although the most commonly used method is ventriculoperitoneal shunts, for example, in the presence of peritonitis, a ventriculoatrial shunt can be used as an alternative. In a situation where the ventriculoatrial shunt cannot be tolerated, the ventriculopleural shunt can be used as an alternative method.

3.2.1. Ventriculoperitoneal shunt

In conditions where endoscopic third ventriculostomy is not suitable or has failed even though it has been performed, the standard shunt procedure for hydrocephalus is the ventriculoperitoneal shunt procedure. The right frontal or parieto-occipital approach is often used for a ventricular catheter. For the peritoneal catheter, a mini-laparotomy is performed with an incision that fits the right superior lateral of the umbilicus. Ventricular and peritoneal catheters are connected with a valve and anti-siphon device under the skin.

3.2.2. Ventriculoatrial shunt

Although ventriculoatrial shunts have long been used as a standard shunt procedure for hydrocephalus, they were replaced by ventriculoperitoneal shunts in the 1970s. (6-9) The main reason for this is the severe complications of the ventriculoatrial shunt procedure and the ease of performing the ventriculoperitoneal shunt procedure. In addition, especially in children, due to the fixation of the distal catheter in ventriculoatrial shunts, keeping the distal catheter short and replacing it as a result of linear growth has been another problem. However, it remains crucial as an alternative shunt procedure in peritoneal pathologies. Standard right frontal and parieto-occipital approaches are applied for the ventricular catheter. For the atrial catheter, a mini-incision is made at the anterior edge of the sternocleidomastoid muscle in the cervical region, and the distal catheter is inserted into the atrium through the jugular vein. The catheters are connected by subcutaneous tunneling with a valve and anti-siphon device.

3.2.3. Ventriculopleural shunt

Although its capacity for absorption of the cerebrospinal fluid is limited, the ventriculopleural shunt procedure remains an alternative to other shunt procedures. It is a valuable shunt procedure for unsuitable endoscopic third ventriculostomy in patients with cardiac and peritoneal pathologies. However, due to the high risk of subpleural effusion, ventriculopleural shunts are not the first choice among shunt procedures. While standard right frontal and parieto-occipital approaches are applied for the ventricular catheter as in other procedures, anterior axillary or mid-axillary thoracotomy is applied at the right third and fifth costas for the pleural catheter, and the distal catheter is placed in the sub-pleural area. The catheters are connected by subcutaneous tunneling with a valve and anti-siphon device.

4. Shunt complications

Shunt complications usually consist of shunt occlusions and shunt dysfunction due to shunt infections. However, hemorrhage or malposition due to perioperative ventricular catheterization may also result in shunt dysfunction. In addition, distal catheterization complications specific to shunt procedures or improper selection of the shunt valve can be counted among the complications of the shunt.

4.1. General complications of shunt procedures

Even if there are complications specific to the application technique in all shunt procedures, there are some surgical complications that can be seen in all shunt surgeries. These are hemorrhage, surgical malposition, and surgical infections during surgery. In endoscopic applications, hemorrhage is usually noticeable during the procedure. In extra-thecal shunt procedures, the choroidal plexus rarely bleeds during ventricular catheterization. Therefore, in ventricular catheterization, the catheter position is usually planned to be away from the choroid plexus. (10) So, the frontal or parieto-occipital approach is preferred. In ventricular catheterization, CSF draining from another subarachnoid space instead of the intraventricular space usually results in shunt obstruction or inadequate operation. Therefore re-operation is generally preferred after cranial imaging. Other surgical complications are listed under subheadings.

4.1.1. Infective complications

A common complication in all shunt procedures is infection. Therefore, some precautions are taken during surgery. These measures are not to take more people to the surgical room than necessary, to change gloves frequently at every stage during surgery, and to touch the equipment of the shunt procedures as few people as possible. Especially in extra-thecal shunt procedures, the risk of shunt complications is between 4% and 30%. (11-13) The most common agent of shunt infection is gram-positive coagulase-negative staphylococci, which is reported with a risk of between 17% and 78%, and Staphylococcus Aureus is the most frequently reported of these. (13, 14) In case of suspicion of shunt infection, the patient has signs of central nervous system infection. These findings are the findings of meningeal irritation, unconsciousness, and fever. Frequently, shunt infection leads to shunt dysfunction, and hydrocephalus manifestations result from shunt occlusion. External ventricular drainage is performed during the shunt infection.

4.1.2. Mechanical complications

Mechanical complications in shunt procedures are one of the important causes of shunt dysfunction, especially in extra-thecal shunt procedures. If mechanical complications in the ETV procedure are to be mentioned, this only includes injuries related to using endoscopes during the perioperative ventricular intervention. These can range from hemorrhages to direct parenchymal injuries. Mechanical complications in extra-thecal shunt procedures include a mechanical problem that may arise from anywhere in the shunt system. These problems include shunt occlusion, discontinuation, fracture, and shunt migration. Shunt occlusion is when the ventricular catheter is occluded with the choroid plexus, or the distal catheter is occluded due to localization according to the selected shunt procedure. The result is shunt dysfunction due to shunt obstruction. It is reported that there is no valve-induced difference in terms of the risk of shunt occlusion. (15-18) Shunt discontinuation refers to discontinuing the connections between the catheters and the valve. Non-absorbable sutures should be used to prevent shunt discontinuation. Shunt migration may occur in the early postoperative period due to insufficient fixation of the shunt system to the subcutaneous tissues at the ventricular catheter or valve level, or it may develop due to linear growth in pediatric patients in the late period. Shunt systems can calcify over time. In this case, especially in pediatric patients, the shunt system can break out from any part due to height growth and is called shunt fracture.

4.1.3. Functional complications

Functional complications in shunting procedures are associated with insufficient or excessive CSF drainage. Insufficient CSF drainage in ETV indicates the failure of ETV application and extra-thecal shunt procedures are performed due to the hydrocephalus. Functional complications in extra-thecal shunt procedures are directly related to shunt valve selection and anti-siphon devices. If the shunt valve is insufficient, CSF drainage remains inadequate, and hydrocephalus continues. Over-draining the CSF by the shunt valve or the absence of anti-siphon device results in hyper-drainage. In the case of hyper-drainage, a slit ventricle is observed on imaging with signs of intracranial hypotension. In both cases, shunt revision is required. It is also possible to have subdural effusion, subdural hematoma, slit ventricular syndrome, and shunt-associated craniosynostosis due to hyper-drainage. Selecting a programmable shunt in extra-thecal shunt procedures may be an alternative to prevent functional complications.

4.1.4. Late complications

Patients with meningomyelocele are shunt-dependent from the first days of life until the end of their lives. Therefore, they are the most exposed patient group to late complications of shunts. Some endocrine disorders can be seen in the late period in patients with shunts. Growth hormone insufficiency, early puberty, and infertility can be seen due to intracranial hypertension. (19-21) Obesity associated with hypothalamic dysfunction may occur. (22) Chronic headaches were reported in 44% of shunt patients. (23) Epilepsy was reported in 30% of patients with shunts without a diagnosis of an intracranial mass. (24)

4.2. Specific complications of shunt procedures

Intra-thecal or extra-thecal shunt procedures have different surgical anatomies and contain different complications specific to their procedure type and localization. While these complications are related to endoscopes in intra-thecal shunt procedures, they include some different complications related to localizations where the distal catheter is inserted in extra-thecal shunt procedures.

4.2.1. Complications of Endoscopic 3rd Ventriculostomy

The most important complication in Endoscopic Third Ventriculostomy is the complication of hemorrhage during a ventricular intervention. The most common cause is bleeding from the choroidal plexus. The most critical hemorrhage complication is bleeding at the base of the third ventricle due to injury to the basilar and pontine vessels. To avoid losing the visual ability when a hemorrhage is encountered, it is necessary to wait for the bleeding to stop with abundant irrigation without removing the endoscope and to prepare for endovascular interventions if the bleeding does not stop. In case of withdrawal of the endoscope, the intra-ventricular area fills with blood, and the ability of vision with the endoscope is lost. Other ETV complications include pseudo-meningocele, wound infection, meningitis, neurological deficits, endocrinopathies, and perioperative seizures. (25)

4.2.2. Complications of ventriculoperitoneal shunt

Complications specific to ventriculoperitoneal shunt procedures are those of the peritoneal area, which is the localization of the distal catheter. The risks of these complications increase due to adhesions in the previous history of abdominal surgery or infection or a history of ventriculoperitoneal shunt revision. There is a risk of destruction and migration of the peritoneal catheter in different anatomical regions over time. The areas where the distal catheter is migrated may be the gallbladder, bladder, oral cavity, anus, scrotum, umbilicus, heart, thorax, and pulmonary artery. (26-34) Abdominal pseudocyst formation is another defined complication, and its incidence has been reported as 1% to 4.5%. (35, 36) The inflammatory process has been responsible for the etiology of abdominal pseudocyst formation. The main reasons are infection, previous abdominal surgery, and silicone allergy. (37-39)

4.2.3. Complications of ventriculoatrial shunt

Complications specific to ventriculoatrial shunt procedures include the complications of the cervical region, localization of the distal catheter, and cardiovascular complications. As a result of the cervical venous intervention, hemothorax, pneumothorax, arterial injury, hematoma, or catheter malposition may develop. (40) Thromboembolism due to permanent shunt catheter may result in pulmonary hypertension and cor pulmonale. Prolonged infection from Staphylococcus Epidermidis can cause shunt nephritis. (41) Shunt nephritis is glomerulonephritis caused by an accumulation of immune complexes in the glomerular basement membrane due to chronic immune activation. (42) The incidence of shunt nephritis is between 3.5% and 11%. (43, 44)

4.2.4. Complications of ventriculopleural shunt

Complications specific to ventriculopleural shunt procedures are those related to the pleural area, which is the localization of the distal catheter. The incidence of ventriculopleural shunt complications is between 10% and 20%. (45, 46) The most common complication is pneumothorax and pleural effusion. (47, 48)

5. Conclusion

Although there are many complications in all shunt procedures for hydrocephalus, they are significantly higher in extra-thecal shunt procedures. Therefore, endoscopic intervention is the most appropriate option to avoid shunt complications in appropriate cases.

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CHAPTER III

SURGICAL COMPLICATIONS OF SPINAL METASTASIS

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1. Introduction

Surgery for metastatic spine disease includes all the risks of non-oncologic spine surgery, as well as complex factors such as radiotherapy, chemotherapy, coagulopathies, and the medical fragility of oncology patients. Low albumin level, additional comorbidities, pathological fractures, involvement of more than three vertebral levels, a combined approach, age, tumor type, blood transfusion, and Charlson comorbidity index have been reported in the previous studies as factors associated with complications of surgical treatment (1,2). Surgical methods that can be performed in spinal metastases; can range from minimally invasive procedures such as percutaneous biopsy or vertebroplasty to relatively large surgeries such as intradural and intramedullary tumor resections through multi-level decompression and instrumentation. In various studies, it is observed that the complication rates after spinal metastasis surgery range from 10% to 66.7% (3). In a study of patients undergoing surgery for cervical, thoracic, or lumbar metastatic spine disease, the complication rate within 30 days after surgery was reported as 32%, and 18% of patients had at least one reoperation (4).

Like all surgeries, there is a possibility of complications in metastatic spine surgery at all stages, starting from the preoperative preparation stage, including the intraoperative and postoperative periods. In addition, complications that may develop may include general medical and anesthesia-related complications, while the content of this section is complications related to surgery.

Surgical complications include neurological complications, spinal cord damage, cerebrospinal fluid leakage, dural injury, vascular injuries, esophagus and airway injuries, instrumentation failure, and wound-related complications (3).

2. Surgical Complications

2.1. Spinal Cord Injury and Neurological Complications

Neurological complications are common complications after spinal surgery. In addition to temporary or permanent motor deficits, it includes sensory deficits and changes such as radiculopathies and dysesthesias. Neurological complications consisting of a wide scale can be observed with a frequency of 0.6% to 14.5% (5,6). While there is a risk of neurological complications and spinal cord injury at every level of the spine, cervical and thoracic spine surgery approaches, in which more extensive bone resections such as corpectomy are applied, increase the risk even more (6,7). In these regions, the spinal cord has not yet terminated, and there is a risk of direct damage to neural tissue. At the same time, the Adamkiewicz artery, which runs in the thoracic region, has a feeder feature, and the risks of occlusion and injury of this artery are additional risk factors. (7). In their retrospective study, Biega et al. reported the rate of postoperative neurological deficits as 1.5% (8). In addition, they stated that the deficit developed immediately after surgery in 25% of the cases that developed deficits and that it developed slowly in the remaining 75%. While epidural hematoma was observed as the cause in rapidly appearing cases, the cause of slow-appearing cases could not be determined. There was a partial improvement in 12.5% of the patients, and no improvement was observed in the remaining 87.5%. De Ruiter et al. reported neurologic deficits with a rate of 3% (2 patients) after surgery; one of them was weakness in the iliopsoas muscle after anterolateral approach and paresis due to spinal cord injury in one patient (9). Dea et al. reported a 5.9% transient neurological deficit and 0% permanent deficit, while Bollen et al. reported a 9.4% post-surgery neurologic deficit (10,11). Tarawneh et al. found a 3.3% incidence of general neurological deterioration in their review study and stated that it was the most common complication (12).

2.2 Dural Injury and Cerebrospinal Fluid Leakage

In addition to the increase in adhesions and fibrosis due to tumor and radiotherapy in patients with spinal metastasis, the risk of preoperative dural injury increases due to thinning of the dura. According to the study of Igoumenou et al., the risk of dural injury can reach up to 16% in spine metastasis surgery (3).

2.3 Vascular Injury

While major vessel injuries in spinal metastases can be counted among the existing risks, the risk increases even more in surgeries involving larger areas, such as spondylectomy and operations with large vessels in the surrounding area (13). In regions such as the cervical region, where large vessels can be seen in the surgical field, vascular injury can be recognized and treated during surgery, while blunt injuries and vascular dissections can be noticed by clinical follow-up in the postoperative period (14,15). In case of hypotension or low hemoglobin in the postoperative period at other levels where vascular injuries may not be noticed during surgery, it causes suspected vascular damage, and imaging such as CT angiography is recommended (15).

2.4. Airway Injuries

Obstructions occurring in the first hour after extubation is generally associated with a residual neuromuscular blockade or narcotic drug-induced hypoventilation, and airway obstructions occurring up to the first three days are related to surgery of the cervical region(16). Hematoma in the first 12 hours and abscess formation after the 3rd day indicates cerebrospinal fluid leakage or instrumentation failure (17–19).

2.5. Esophageal Injuries

The incidence of esophageal injury, a feared complication of anterior cervical spine surgery, is 1.6%, and the risk increases even more in corpectomies involving more than one level (3,20). Especially the fragile esophagus due to the metastasis and radiotherapy increases the risk of rupture. While esophageal ruptures are associated with high mortality, good results can be obtained with close follow-up and early intervention (21). Even though esophageal ruptures are associated with increased mortality, good results can be obtained with close follow-up and early intervention. If the injury is noticed intraoperatively, the essential treatment is primary repair. Repair includes suturing with surgical absorbable sutures and insertion of a nasogastric catheter during the operation, and antibiotics should be started prophylactically. If possible, surgery should be abandoned at that time, and the patient should be followed up with an oral stop. After the follow-up, barium esophageal radiography or endoscopy should be performed, and the surgery should be continued later. (3). If the injury is not observed during surgery, pain and difficulty in swallowing, odynophagia, subcutaneous emphysema, swelling at the surgical site, and fever should be considered early signs. In the late period, recurrent pneumonia, neck pain, abscess formation in the wound area, sepsis, and mediastinitis are also among the findings of esophageal injury (15). In esophageal injury detected in the late period, the primary treatment is esophageal repair; debridement can be added to the treatment if necessary.

2.6. Dysphagia and Dysphonia

These complications, which may develop due to esophageal or laryngeal nerve damage during anterior cervical surgery, can be observed widely. Dysphonia is mainly observed in up to 2.5% of cases due to damage to the recurrent laryngeal nerve or direct compression of the vocal cords and usually regresses spontaneously (3). While these complications may develop due to manipulation of the superior laryngeal nerve, pharyngeal plexus, hypoglossal nerve, and recurrent laryngeal nerve during surgery or soft tissue swelling, they may also occur due to instability and kyphosis of the thoracocervical junction (22–24). In the study of De Ruiter et al., in patients operated on for metastatic spine, temporary hoarseness due to traction of the recurrent laryngeal nerve was reported with a rate of 3.3% (9).

2.7. Wound Infections and Dehiscence

Wound complications, which are the most common complications of spine metastasis surgeries with a rate of 9.5%-11%, are among the most critical complications with their features such as causing repetitive surgeries, increasing costs, and mortality and morbidity (3,15,25). Patients with spinal metastases are generally inadequate in nutrition. Other diseases such as diabetes mellitus, heart disease, hypertension, radiotherapy-chemotherapy history, previous surgery, hospitalization due to infection, underlying neurological disorders, and drug use also increase the risk (7,15). In another study, predictive risk factors for surgical wound complications in patients with spinal metastases were identified as female gender, smoking, adjuvant treatments (chemotherapy, radiotherapy, corticosteroids), anemia, malnutrition, alcoholism, prolonged surgical time, and history of previous surgery (26). Wound infections are mainly observed after discharge and detected on an average of 13 days after anterior cervical surgery and 17 days after posterior lumbar surgery (27). In addition, while hypothermia was advocated in spine surgery to avoid wound infection in previous studies, it is argued that it is more beneficial to maintain normothermia in the study of Swann et al. (15).

2.8. Complications Associated with Instrumentation

While the necessity of fusion in spinal metastases was controversial in the past, fusion is considered necessary, especially to avoid inadequate instrumentation due to increased overall survival, and cement reinforcement and double rod techniques can be used to improve the strength of the instrumentation (7). In addition, the instrumentation could increase the amount of resection in spinal metastases surgery. Instrumentation-related complications in metastasis surgery are similar to those in general spinal instrumentation surgeries, such as screw malposition, fixation instability, and rod breakage, and the overall incidence can reach 5% (3). In the study by Amankulor et al., it was revealed that 2.8% of patients who underwent posterolateral decompression and posterior stabilization without additional anterior fixation had instrumentation failure and required revision (28). In addition, in the same study, it was reported that patients with chest wall resection and stabilization greater than six levels had a statistically significantly higher risk of symptomatic instrumentation failure. De Ruiter et al. found 5% instrumentation failure, and in one of these cases, failure was observed in the early period and the other two in the late period (9). Bellato et al. found incompetence at a rate of 8% in their study; Most commonly, osteolysis was observed along the screw, followed by avulsion in the proximal or distal screws (29). Elsamadicy et al. examined the 30-day complication and unscheduled readmission rates associated with the resection of metastatic spinal tumors in 30 patients. The 30-day readmission rate was 9.7%, and the 30-day instrumentation failure rate was 3.3% (30). When all previous studies were evaluated, Tarawneh et al. reported an overall incidence of 2.0% instrumentation failure after metastasis surgery (12).

In addition, in patients who underwent vertebroplasty and kyphoplasty in addition to instrumentation surgery, additional complications specific to these surgeries can be observed. While the risks associated with these procedures are uncommon, serious complications can occur. These risks include spinal cord compression, nerve root compression, deep venous embolism, and pulmonary embolism, including cardiovascular collapse (31,32).

3. Conclusion

Considering that the complications developing after metastatic spine disease are a heavy burden not only for the patients but also for the health system, it becomes more important to be informed about the complications and to be able to provide the appropriate management of the complications. In this patient group, which includes all the risks of spine surgery, preoperative preparations and the postoperative follow-up process should be planned without forgetting additional oncological factors.

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CHAPTER IV

NEUROVASCULAR SURGERY COMPLICATIONS

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1. Introductıon

Cerebrovascular diseases (CVD) are pathologies with a high need for intervention by choosing one or more of the different treatment modalities. In other words, they are pathologies that can result in high mortality and morbidity if they are followed without treatment. While successful management can achieve life-saving and absolutely good results, it includes complications that can cause catastrophic results, permanent sequelae and high need for care. (1-3)

There are no satisfactory data on the overall complication rates of cerebrovascular surgeries (CVS) in the neurosurgery literature. Reviews of data reported separately for each of the pathologies evaluated under the CVD subheading show that overall complication rates for CVS can range from 2% to 17%. (1) On the other hand, in the study of Michalak et al., examining the mortality and complication rates of 1141 CVS applied cases within one month postoperatively, on the database of the National Surgical Quality Improvement Program (NSQIP); The overall complication rate was estimated at 30.9%, which is almost double the review estimates. (4)

The CVD designation indicates specific pathologies such as intracerebral aneurysms, cerebral arteriovenous malformations and intracerebral cavernomas. SVCs, on the other hand, consist of microsurgical operations and endovascular procedures performed by craniotomy for these specific pathologies. Therefore, all CVDs; In microsurgical, endovascular or combined treatment management, both methods contain separate risks against all complications. In addition, microsurgical operations carry the risks of general complications related to craniotomy. Below, the complications for both treatment modalities and their outlines and information on the management of these complications are shared.

Table 1: Neurovascular Surgery Complications

Craniotomy	**Intracerebral Aneurysms**		**Arterivenous Malformations**
	Complications Due to Microsurgery	**Complications Due to Endovascular Treatment**	
• Cerebral Edema	• Direct Tissue Damage	• On Input/ Shutdown Devices	• Intraoperative
• Cerebral Contusion	• Clip Placement	*Retroperitoneal Bleeding*	• Postoperative
• Cerebral Hemorrhage	*Slip in Clip*	*Pseudoaneurysm*	
• Cerebral Ischemia	*Incomplete Clipping or Incomplete Closing of Clip Legs*	*Femoral or Iliac Artery Injuries/ Dissections*	
• Epileptic Seizure	*Laceration on Aneurysm Neck*	*Distal Thromboembolism*	
• Hydrocephalus	*Remaining Surrounding Textures in the Clip*	• Contrast Substance	
• CSF Fistula	• Sacrification of the Parent Artery	*Contrast Nephropathy*	
• Infection	• Intraoperative Rupture	*Contrast Allergy*	
		• Coil	
		Coil Protrusion	
		Rupture	
		Coil Stretching	
		• Dissection	
		• Embolism	

2. General Cranıotomy Complıcatıons

The most important factor in determining the complication risks of the applied surgical techniques is the inadequate, irregular and biased recording system.

Unfortunately; This table still continues as a global problem. In studies conducted on databases created with checklists developed to eliminate the effectiveness of this negative factor, the overall complication rates due to craniotomy are reported to be between 23-24%. (5,6)

2.1. Cerebral Edema

Cerebral parenchymal edema is one of the inevitable complications of surgical manipulations that can lead to different symptomatologies in correlation with the degree of manipulation. Mild cerebral edema may cause delays in the return of normal neurological functions, but may present as the development of severe edema, advanced cognitive dysfunction, seizures, and neurological deficits. In addition, malignant cerebral edema can lead to cerebral herniation and even death.

The first of the three main components of the pathogenesis of cerebral edema is hemodynamic changes that develop after damage or thrombosis of the drainage vessels. The second is the activation of the cytotoxic cascade due to direct damage to the cerebral parenchymal tissue, and the third component is ischemic tissue damage caused by prolonged retraction. The coexistence of one or more of these three components determines the depth of the clinical picture. (7)

Generally, the presence of postoperative cerebral edema is self-limiting. Close clinical and radiological follow-up, euvolemia and keeping systolic arterial pressure within normal values are sufficient. However, diuretics such as furosemide may be used, along with osmotic agents such as mannitol or hypertonic saline, if the clinician requires it based on the current symptoms. In cases of malignant edema with clinically unfavorable progression, surgical interventions such as decompressive craniectomy or lobectomy may be required.

In order to reduce or even prevent postoperative cerebral edema; It is important to minimize venous compression during the operation with proper positioning, to avoid neural parenchymal retraction as much as possible, to protect the drainage veins as much as possible, to ensure adequate intraoperative hydration and to keep cerebral blood flow and cerebral perfusion within ideal limits.

2.2. Cerebral Contusion

Just like cerebral edema, it is a complication that can lead to different symptomatologies as a result of surgical manipulations, in correlation with the degree of manipulation. It may be symptomatic in relation to its localization and dimensions. Since it occurs as a result of direct effects on the neural parenchyma or vascular structures, minimizing the retraction, applying the dissection sensitively, paying attention to the continuity of the vascular circulation are the most important preventive measures. If hemorrhagic transformation is seen, surgical decompression can be applied.

2.3. Intracerebral Hemorrhage

Intracerebral hemorrhage is one of the most common and catastrophic complications after intracranial surgery. It is an important cause of postoperative morbidity and mortality. Reported rates of postoperative intracerebral hemorrhage vary depending on the definitions. Regardless of the amount of bleeding, the incidence of hemorrhage in the operating site varies between 10% and 50%, based on radiological detection. (8) On the other hand, the rate of hemorrhages that may require surgical intervention is reported to be between 0.8% and 6.9%. (8.9)

Hemorrhages that are small in amount and do not cause any additional symptomatology in the patient can be followed with the goal of spontaneous resorption. However, secondary surgeries are the only option in the management of moderate-to-high amount of hemorrhages that create additional clinical findings and radiologically contain this risk. Starting from this point; Preventive measures are extremely important. Some of those; ensuring the maximum level of hemostasis, closing the layers in accordance with the anatomy, maintaining the ideal arterial pressure and intracranial pressure, especially after hemostasis and in the wake-up phases. (10)

2.4. Cerebral Ischemia

The risk of developing ischemic cerebrovascular disease after craniotomy surgeries has been reported as 0.73%. (11) Postoperative cerebral ischemia events may be of arterial or venous origin.

Arterial infarctions are usually caused by intraoperative injury or sacrifice of major arteries. Therefore, many of them can be detected during operation. However, peropal damage to small but vitally important main feeding or perforating arterial structures that feed some deep brain structures can be overlooked, and the consequences of these can be observed as neurological deficits in the postoperative period. It should not be forgotten that vasospasm, which may develop without any arterial injury during surgery, may cause similar clinical findings in vascular lesions such as intracerebral aneurysms and arteriovenous malformations.

Surgical experience has been associated with the incidence of arterial injury. Insufficient knowledge of vascular anatomy, inadequate skills in microsurgery, inappropriate dissection techniques, and lack of expertise in vascular repairs are factors associated with a higher incidence of vascular injury. In the management of developing infarction, intracranial pressure control, antiedema treatment modalities and even decompressive craniectomy applications can be performed if necessary. On the other hand, since the most important factor associated with arterial injury is the "surgeon", increasing education on related techniques may be the most effective preventive method.

Venous infarctions occur due to injury or sacrifice of the cortical main drainage vessels or venous sinuses. Besides direct venous injury, other important causes of venous infarction development include venous thrombosis or sinus thrombosis. Among the reasons; These include inadequate perop saline irrigation, prolonged and rigid retraction and manipulations, intraoperative hypotension, bleeding control, or the use of inappropriate pressure or hemostats for ligation of proximal veins. Management requires similar disciplines with arterial infarctions. However, it should not be forgotten that venous infarctions tend to have a relatively more aggressive course compared to arterial ones. For this reason, they require more careful and rapid intervention compared to arterial infarctions.

2.5. Epileptic Seizures

Postoperative seizure may occur immediately after the operation or during the recovery period. Early postoperative seizures are reported in 10% to 20% of supratentorial surgeries. Intracranial masses may occur due to cortical irritation after surgical manipulations of arteriovenous malformations, or they may develop secondary to a serious underlying complication such as postoperative hemorrhages, cerebral edema or infarction. Other causes of seizures in the postoperative period include known epilepsy diagnosis, electrolyte imbalance, hypoxia and anesthetic drugs. (12)

Almost no systematic studies or clinical trials have proven any benefit from the prophylactic use of antiepileptics for intracranial surgery. (12) Despite this, it is undeniable that it has a place in practical application. Intraoperative measures include minimizing retraction, avoiding excessive coagulation, frequent irrigation, and ensuring proper hemostasis.

2.6. Hydrocephalus

Postoperative hydrocephalus is an important complication that can be observed after interventions in lesions around the third or fourth ventricle. Although the causes include intraoperative bleeding or postoperative edema of the surrounding tissues, another important reason is subarachnoid hemorrhages that prevent CSF absorption at the arachnoid villus level.

Acute hydrocephalus is a complication that can be fatal if not treated promptly, as it causes an increase in intracranial pressure. Patients with postoperative hydrocephalus deserve management with temporary CSF diversion techniques (external ventricular drainage / lumbar drainage) until the ventricular system is cleared. Some of these may need permanent CSF diversions. For example, the rate of hydrocephalus development in the early period for intracerebral aneurysms is 6-67% (mean 30%), while the proportion of cases requiring permanent CSF diversion after the second week is reported to be approximately 48% of cases requiring temporary techniques. (13,14)

2.7. Cerebrospinal Fluid Fistula

Although fistula of cerebrospinal fluid can complicate the healing processes of craniotomy cases, chronic fistula is extremely rare. In most cases, CSF leakage is the result of improper closure techniques, including improper dural closure, dural rupture due to strain, and improper soft tissue and skin closure. Although CSF leaks are asymptomatic to the patient, persistent leaks can lead to infectious complications such as meningitis, empyema, or brain abscess. In this context, it should be followed closely. (10)

2.8. Infection

Postoperative infections are one of the important causes of postoperative morbidity, and they are also in the first place among the causes of rehospitalization. (15) All reported infection rates after craniotomy procedures are 0.7% to 1.1%. Among these, the rates of postoperative meningitis are 0.5-0.7%.

Postoperative infections can be superficial surgical site infections, deep infections such as cranial osteomyelitis, meningitis, subdural empyema or brain abscess. Another important site of infection is implant infections such as EVD, ventriculoperitoneal shunt, cranial or spinal implants. The development of infection often develops due to violation of the preoperative asepsis/ antisepsis rules. Other causes include postoperative CSF leakage and secondary contaminations.

Management of postoperative infection is appropriate antibiotic therapy. Additional surgical treatments should be planned in addition to antibiotic therapy in the detection of empyema or abscess. (10)

3. Intracerebral Aneurysms

3.1. Complications of Microsurgery

Complications of intracerebral aneurysms (ICA) by craniotomy and microsurgical clipping are not correlated with whether the target aneurysm is ruptured or not (16). Despite this; Patient-related factors such as age, comorbidity, dependency level before treatment, aneurysm-related factors such as symptoms, size, location, configuration and presence of intracerebral hemorrhage, maximum adequacy of preoperative imaging, peroperative technical equipment, and most importantly, surgical experience, are directly correlated with possible complications (1). These factors are also highly effective in the management of the complications.

3.1.1. Direct Tissue Damage

Direct tissue damage includes damage to the cranial nerves, neural parenchyma or vascular tissues, which may occur as a result of direct surgical manipulations as well as indirect effects such as compression and retraction, associated or unrelated to the retractor. Its clinical and radiological manifestations are discussed under the heading of craniotomy complications.

3.1.2. Clip Placement Complications

3.1.2.1. Incomplete Clipping or Incomplete Closing of Clip Legs

It means that the residue aneurysm remains in the neck. It may require remodeling of the aneurysm dome and/or neck with the help of multiple clips or bipolar coagulation. If complete closure is not achieved despite remodeling management by wrappig with muscle tissue or acrylic, hybrid treatment with the endovascular methods can be used.

3.1.2.2. Clip Slip

It is mostly observed in wide-based aneurysms. It can lead to complete or partial obstruction by distortion or folding of the parent arteries. At the beginning of preventive surgical manipulations; After draining the blood in the fundus using a temporary clip, appropriate dissection of the neck can and, if necessary, remodeling with bipolar coagulation, permanent clip placement comes. If there is atheroma plaque, calcification and thrombosis, the same procedure is repeated after endarterectomy.

3.1.2.3. Laceration on Aneurysm Neck

It covers the tears of the aneursym which are still in the first dissection stage. It is usually observed in thin-necked aneurysms or in cases where the neck of the aneurysm dome is attached to the surrounding tissues. It can be managed with the use of multiple fenestration or graft clips.

3.1.2.4. Remaining Surrounding Tissues inside the Clip

It develops as a result of not removing neural tissue, cranial nerves (especially II. and III. CSs) or perforating vascular arteries from the clip site with adequate dissection. Surrounding tissues and clip leg trace should be checked after the clip is placed to avoid from this complication. If necessary, the clip should be replaced.

3.1.3. Sacrification of the Parent Artery

The main goal in aneurysm surgery is to clip the aneurysm together with preservation of the main flow and perforating arteries. In addition to reasons such as the location of the aneurysm, its size, or its relationship with neighboring structures, reasons such as intraoperative rupture or inadequate clipping may occur. Moreover, combined applications of microsurgical and endovascular treatment modalities may not be possible in some cases. In these cases, sacrificing the parent artery and bypassing the saphenous vein or radial artery may be required in order to achieve the main target (1).

3.1.4. Intraoperative Rupture

Intraoperative rupture (IOR) and/or parent vascular injury (PVY) are among the potentially most devastating complications in the treatment of intracerebral aneurysms (1).

Although IOR is more often in the cases that presents with subarachnoid hemorrhage, it occurs in approximately 16.6% to 33% of all aneurysm cases treated with microsurgery (17, 18). The localization, size, morphology of the aneurysm and the relationship of the fundus with the surrounding structures are related to the IOR (18, 19). Even though it is said that surgeons experience has no effect on the rate of IOR (20), it is known that experience and technical repetition increase predictability, stability and efficiency in IOR management over time (21).

As with all other complications, preventive factors are important in IOR. However, it should not be forgotten that; Even if the factors that increase the risk for IOR are known, development may occur independently of the known factors. Therefore, it is very important for the surgeons to be prepared and equipped for IOR management to preventing deadly outcomes.

Prevention of IOR starts with the right patient selection for microsurgical treatment (18). Cerebral retraction should be performed minimally after craniotomy and cisternal dissection can be done to allow maximum exploration and manipulation. The dissection and revealing of the parent artery and perforating arteries are extremely important to protect the parent artery. This careful dissection of the parent artery is vital for application of the temporary clip. The dissection of the aneurysm should be started from the distal part after that the neck should be dissected sharply but softly. Because the management of ruptures from the neck are the most difficult ruptures of the aneurysm sac (18). Neck shaping processes should be done with time carefully for placement of the permanent clips and should not be rushed to prevent any complications. Even if IOR is unavoidable, following the principles of cerebrovascular surgery can limit the risk of the rupture.

In IOR management, the main goal is to explore the localization of the rupture and clip it with the appropriate clip. For this purpose; parent artery should be controlled, and the bleeding should be removed with effective aspiration from the operation area after the temporary clip. Rude, uncontrolled manipulations to the parent artery or the aneurysm should be avoided. Unless, the tear can reach much more uncontrolled dimensions, and iatrogenic injury can deepen. After the secure clipping procedure, the temporary clip can be removed and the parent artery, perforators, and surrounding neural structures should be checked.

In summary; Successful management of intraoperative rupture requires to remain calm for the operator and clear the surgical site from the blood, limit the ongoing bleeding, and securely clip the aneurysm (18).

3.2. Complications of Endovascular Treatment

In adult cases, the risk of developing temporary neurological deficit due to diagnostic angiography is 2.5% and permanent neurological deficit is 1%. In addition, renal failure can be observed as 0.2%, arterial occlusion requiring surgical intervention as 0.2%, hemorrhage requiring surgical intervention as 0.5%, arteriovenous fistula/pseudoaneurysm development as 0.2%. All major complications can be occur as 2% roughly (22).

3.2.1. Complications of Entry and Closure Devices

Complications related to femoral artery catheterization can be observed around 2%. Development of hematoma at the entry site, retroperitoneal hemorrhage, and rarely pseudoaneurysm and arterial dissection are the main complications (23). This risk of complications related to opening and closure process is higher in the patients using antiaggregant and anticoagulant therapies.

3.2.1.1. Retroperitoneal Bleeding

Retroperitoneal bleeding can be a life-threatening situation. If diffuse abdominal pain or flank pain develops after the procedure, immediately i.v. contrast-enhanced whole abdominal tomography should be performed to check the presence of extravasation.

Cases with retroperitoneal bleeding should be monitoring vital values and blood closely in terms of vital values and blood picture, and transfusion should not be delayed if necessary.

3.2.1.2. Pseudoaneurysm

If an enlarging pulsatile mass is observed at the entry site after the procedure, ultrasound should be performed with the suspicion of pseudoaneurysm.

In pseudoaneurysms <2 cm in size; Compression and/or injection of thrombin may be sufficient. Larger sizes of pseudoaneurysms may require surgery or endovascular treatment. In addition, it should be kept in mind that fistula may develop due to pseudoaneurysm formation and vascular surgeons should be consulted.

3.2.1.3. Femoral or Iliac Artery Injuries / Dissections

Dissection risk is less in the micropuncture and double wall puncture methods. The reduction of the flow is the main factor to determine the need for the dissections related to the procedure.

3.2.1.4. Distal Thromboembolism

Extensive atherosclerosis is the main risk of distal thromboembolism. The patients are diagnosed with peripheral doppler ultrasound. If the embolism level is distal to the popliteal artery level, medical and conservative treatments should be planned first, while endovascular procedure or open surgery should be considered for more proximal levels (23).

3.2.2. Complications of Contrast Agent

3.2.2.1. Contrast Nephropathy

It is defined as a 25-50% increase in serum creatinine values or a 0.5-1 mg/dl increase in serum creatinine over a 3-4 day period after contrast use.

This risk is 10 times higher in patients with kidney failure.

Among the preventive decisions, it is important to use the lowest possible dose of contrast and to meet the second procedure requirement after 48 hours, if possible. Pre-procedure acetylcysteine and hydration uses are common, although its benefit has not been conclusively proven.

3.2.2.2. Contrast Allergy

Antihistamine and steroid treatments can be administered 24-48 hours before the procedure and up to 2-7 days after the procedure in the cases with known allergy to contrast material.

3.2.3. Coil Complications

3.2.3.1. Coil Protrusion

It is the protrusion of the coil loop.

If no more fragments come out in the follow-ups with 5-10 minutes intervals, without affecting the circulation, it can be monitoried with antiaggregant without additional intervention.

It usually results in more protrusion, if there is a need to put more coils into the aneurysm, although subsequent coils may be able to retract the overhanging part. In this case, the coils can be fixed to the wall by placing a stent around the neck of the aneurysm.

3.2.3.2. Aneurysm Rupture

The rupture can not be detected, if a balloon is used during the procedure. The balloon is first inflated and the coil is filled into the aneurysm in a controlled manner. However, if the balloon is not used, in case of rupture, a part of the coil is placed inside the aneurysm and outside of the aneurysm.

3.2.3.3. Coil Stretching

When the coil end is stuck, when the coil is pulled back, the coil wire is suddenly opened and it also stretches as you try to pull it.

The incidence of this situation is around 2%, this rate is decreased with new technology coils (22).

3.2.4. Vascular Dissection

The damage caused by the catheter, wire or stent in the intima layer of the vessel is expressed as dissection. If the risk of thrombosis and a decrease in flow are not detected in the dissection, it can be followed up with antiaggregant therapy and most dissections heal in 3-6 months. If the opposite occurs or if there is a case of treatment with a catheter after dissection, a stent can be applied to the dissection area or open surgery can be considered.

3.2.5. Embolism

In order to prevent air embolism and/or thrombus development, infusion of heparinized saline is important.

4. Arterıovenous Malformatıons

In treating cerebral arteriovenous malformation (AVM), microsurgical resection, endovascular and radiosurgery techniques can be used as case-specific or multimodality approaches. Many studies find microsurgical resection superior to other treatment modalities considering the amount of obliteration and complication rates (24-26).

Complications of AVM surgery include intraoperative rupture, hemorrhage, injury or occlusion of feeding arteries, impaired blood supply to the surrounding healthy cortex (stealing phenomenon), and neurological deficits associated with all these. These complications can occur immediately or delay (27).

Risk factors for complications in AVM surgery can be grouped as patient factors, AVMs characteristics, and AVMs location.

Patient factors; include age, cardiovascular, and other medical comorbidities that affect the patient's surgical risk. The use of antiplatelets, anticoagulants, or conditions that cause coagulation disorders increases the risk of perioperative bleeding.

High-risk AVM features; include the presence of aneurysms in the feeding arteries, nidus, or venous drainage. A large venous varicose may mask the nidus or feeding arteries and these dilations must be carefully dissected to prevent rupture. Also, stenosis or narrowing of the drainage vessel will increase the risk, which can increase the pressure in the nidus. (28)

High-risk AVM localization indicates the location in eloquent regions. Like all other surgeries in these localizations, AVM surgeries are also crucial in terms of the risk of neurological deficits.

4.1. Intraoperative Complications

Avoidance of complications and prevention efforts begin with correct patient selection and appropriate treatment planning in AVM surgery. Almost every step should be carefully planned during the microsurgical resection.

Craniotomy should make it possible to dominate the AVM tissue and surrounding neural tissues. Otherwise; Pathological vascular structures and intact tissue feeders or their course in the vascular network cannot be explored. For this reason, undesirable vascular injuries, hemorrhage, ischemia in intact neural tissue, and eventually neurological deficits may be encountered (1,27).

Dissection of the AVM tissue from the surrounding neural structures is very important in terms of surgical planning. The drainage system of the AVM should be closed last. Premature closure of venous drainage as a result of unintentional injuries or inadequate exploration can lead to bleeding and feeding problems with catastrophic consequences. It may cause the surgeon to lose control of the surgical field. Again, feeding arteries should be closed from areas close to the nidus. Otherwise, the closure of non-pathological arteries from feeding arteries to healthy neural tissues may occur due to the vascular network. This may lead to ischemic complications that may result in permanent neurological deficits (1,27).

4.2. Postoperative Complications

Postoperative hemorrhage can be observed at the operation site after inadequate hemostasis. However, two things should be noted: First, the venous drainage of the AVM is closed while the preservation of the main venous bed is of vital importance in preventing postoperative venous infarction and related hemorrhage. Second, leaving small residuals from the AVM nidus may be associated with postoperative hemorrhage. If in doubt, residual presence should be investigated with angiographic imaging.

Restoration of peripheral cerebral perfusion after AVM resection surgery is provided by autoregulation. An impaired autoregulatory capacity may not compensate for increases in arterial flow, ultimately leading to hyperemia, edema, or intracerebral hemorrhage. This situation is called “Normal Perfusion

Pressure Breakthrough (NPPB)". One of the preventive factors is to obliterate if possible and the other is keeping the blood pressure stable (1).

General complications such as venous thrombosis, retrograde thrombosis of feeding arteries, vasospasm, and epileptic seizures may also be seen in the postoperative period.

5. Conclusıon

Although the preventive approaches to the complications of microsurgical and endovascular procedures provide much more effective results than management, the outcome is to some extent unavoidable given the complexity and difficulty of vascular pathologies.

Things to keep in mind regarding the prevention and management of neurovascular complications; appropriate patient-appropriate treatment modality selection, maximum adherence to the principles of treatment modality, and close postoperative follow-up.

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CHAPTER V

RECURRENT LARYNGEAL NERVE PALSY FOLLOWING ANTERIOR CERVICAL DISCECTOMY AND FUSION

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1. Introduction

The anteromedial cervical approach has been used for 70 years to reach particularly C3-T1 vertebral pathologies. (1,2) In 1954 the first anterior approach to the cervical spine to perform discectomy, Smith and Robinson published a patient they operated using the graft known by their name. (3) Later, in 1958, Cloward published the circular graft in which he described an anterior approach using instrumentation and retractors to approach the spinal canal and eliminate pathology. (4) The necessity of fusion started to be discussed in the anterior intervention, which was initially applied by adding fusion, and in 1960, Hirsch reported that discectomy without fusion also gave successful results in the treatment of cervical radiculopathy. (5) With the development of internal fixation, instrumentation, and retraction devices, and the introduction of the microscope into surgical treatment, anterior cervical discectomy and fusion (ACDF) has become the most commonly performed surgical procedure for cervical disc herniation. (6) The recurrent laryngeal nerve (RLN) palsy is frequently reported as a complication associated with ACDF. (7–10) The RLN is vulnerable, with serious complications on a spectrum from hoarseness, vocal fatigue, dysphonia, impaired phonation, dysphagia, aspiration to impaired cough reflex, airway obstruction, stridor to permanent tracheotomy awaiting surgeons if they do not pay attention to the course and location of the nerve. (11)

2. Cervical disc herniation

The most common symptom in cervical disc hernias, which is one of the broad spectrum consequences of degeneration of the spine, is neck and arm pain. (3) Generally neck pain is self-limiting and can resolve within nonsurgical treatments. (12) Conservative treatment approaches can be listed as bed rest, non-steroidal anti-inflammatory drugs, muscle relaxants, steroids, cervical collar, physical therapy methods, epidural or nerve root blocks and other minimally invasive interventions. (13)

Clinically cervical radiculopathy develops due to compression of the nerve root passing through the neural foramen. It presents with a clinical picture characterized by varying degrees of pain, motor strength, sensory and reflex losses depending on the level affected. When a radiculopathy and its clinico-radiological correlation is present within sudden neurological deficit or progressive pain under conservative treatment, surgery is recommended. (14) Cervical disc herniation can be treated by different surgical procedures. Mazas et al. analyzed its every available surgical options; ACDF remain the gold standard for surgical treatment of cervical disc herniation. (5)

3. Operative technique: ACDF

In the supine and slightly reverse Trendelenburg position, a soft pad was placed beneath the scapula. To obtain slight extension to the neck light traction was applied to the cervical spine. After radiological level determination via intraoperative fluoroscopy, a transverse incision was made on the right side through skin and subcutaneous fat for a right-handed surgeon. Longitudinal skin incision was considered appropriate in patients with long, thin neck and kyphotic deformity. The bleeding was controlled using bipolar electrocautery.

The anteromedial approach was used to expose the intervertebral disc space and vertebral body. The platysma muscle was carefully cut in line with the incision to avoid cutting the large superficial veins. The deep fascia was identified and divided laterally to the anterior border of the sternocleidomastoid muscle (SCM). After careful dissection and adequate soft tissue mobilization via hand retractors, the surgical field was created with the trachea and esophagus medially, SCM and carotid sheat laterally down to the prevertebral fascia (**Fig. 1**).

The vertebral corpus was palpated. The anterior longitudinal ligament (ALL), the anterior face of the intervertebral disc and the longus colli muscles were observed. At this stage, the vertebral level was checked radiologically. The prevertebral fascia and ALL were separated from the midline, and subperiosteal release of the longus colli muscle was achieved. Self-retaining automatic retractors were installed. A pre-measured unicortical screw was placed in the neighboring vertebrae and a Caspar automatic distractor was applied on it. Medially, the blunt retractor tip of the Cloward retractor system was placed below the longus colli muscle.

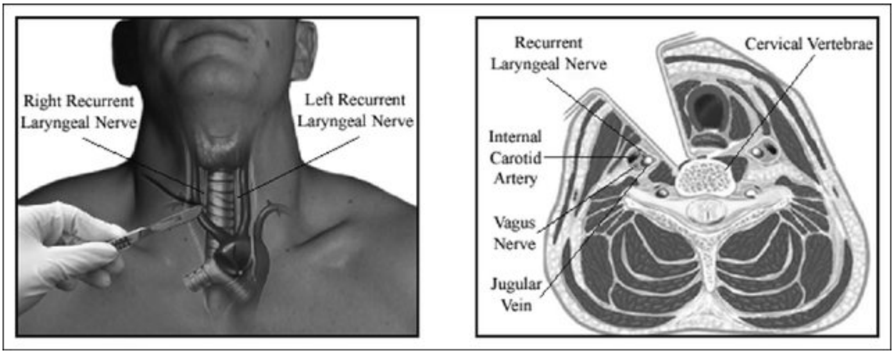

Fig. 1: Cross-sectional anatomy of neck showing retractor placement used for ACDF and RLN. (Figure was adapted from Gowd et al. 2016) (15)

The surgery continued under the microscope after this stage. ALL and the annulus were incised with a rectangular no.15 scalpel tip. Discectomy was performed using angled curette and pituitary forceps. Luschka joints were well seen bilaterally and the disc was completely cleared. During discectomy, the posterior longitudinal ligament (PLL) was approached carefully and it was investigated whether there was a tear or a defect in it. If there was a defect, the back of the PLL was carefully palpated with a small nerve hook and the free part was searched. (16,17)

When the discectomy within foraminotomies were complete, the disc space was measured to decide on appropriately sized graft. Fusion with cage or prosthesis was performed for each patient. Allograft bone pieces were filled into the cage and used for fusion. The main goal of interbody graft in ACDF is to restore disc height. In a systematic review of techniques for cervical interbody support, no single graft type was found to be superior to another. (8,18)

After completion of instrumentation, the wound was checked for hemostasis. The platysma muscle and subcutaneous tissue were closed with interrupted absorbable sutures. Before extubation, the patient was placed in a flexible cervical collar.

4. Anatomy

While performing the anteromedial approach to the subaxial cervical region, injury to important anatomic structures have been reported. The trachea and osephagus, the middle portion of the RLN, the external branch of the superior laryngeal nerve (SLN), the cervical sympathetic truncus, and the spinal accessory nerve are encountered at this approach (7,19). To understand ACDF complications, the anatomy and nerve supply of the larynx should be studied (**Fig. 2**).

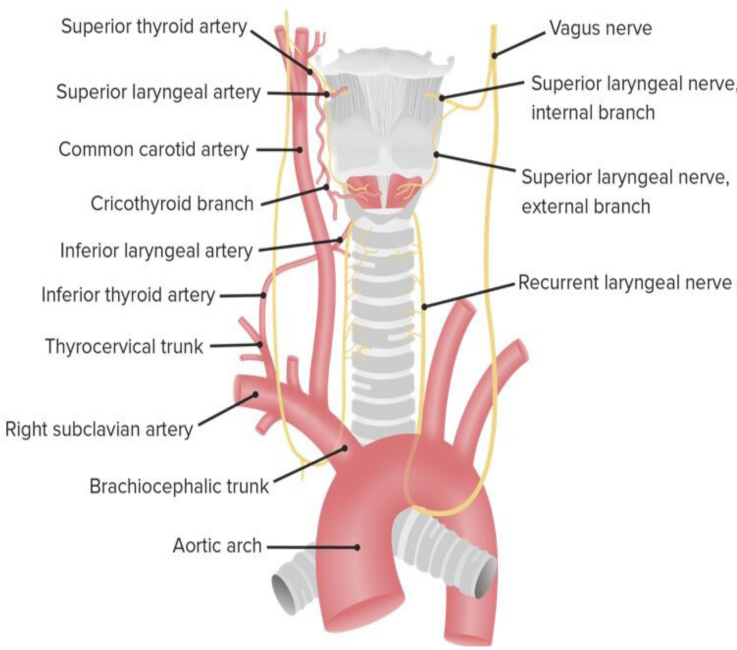

Fig.2: The larynx blood supply and innervaiton. **(**Figure was adapted from Drake et al. 2019, from Gray's Anatomy for Students, 4th Edition) (21)

The larynx is innervated on both sides by branches of the vagus nerve. The RLNs arise from the vagus nerve, the left one at the aortic arch and the right one at the right subclavian artery. After branching, the nerves typically ascend to the larynx in a groove between the trachea and esophagus. The RLN supplies sensation to the larynx below the vocal cords. It innervates all laryngeal intrinsic muscles except the cricothyroid.

The posterior cricoarytenoid muscles, the only muscles that can open the vocal cords, are innervated by the RLN. Unilateral RLN paralysis results in an inability to adduct and abduct the vocal cords. Inadequate laryngeal closure during phonation results in a raspy voice, hoarseness with increased vocal effort, and dyspnea with exertion. There is a higher risk of aspiration due to loss of sensation in the glottis and incomplete closure of the vocal cords. (20)

5. RLN injury incidences

The incidence of RLN injury after ACDF in the literature, Robinson *et al* reported postoperative RLN palsy after ACDF was 7.1%, Contrariwise, Tew and Mayfield in their series only 0.9% and finally Bertalanffy and Eggert was 1.1%. (8,9,22) In ACDF series by Morpeth and Williams, they found that postoperative RLN palsy was 5% (21 of 441 patients). (23) In a retrospective study by Fontas et al. to investigate the complications associated with ACDF, symptomatic RLN palsy occurred in 3.1% (32 of 1015 patients). (24)

6. Mechanism of injury

The patophysiology of RLN injury includes direct injury to the nerve during exposure, indirect injury during traction, and postoperative edema. (1,18,25) Prevention for direct injury, there are certain rules in the surgery. In addition to surgical anatomy knowledge, tissue must be respected. Care in handling blunt and sharp instruments, retraction of the visceral tissues has to be gentle.

The traction injuries can be considered stretch-induced neuropraxia, which is the mildest form of peripheral nerve injury. (1) During surgery, incorrect application of the retractor or overretraction of the larynx and other visceral structures and entrapment of the RLN between the inflated cuff of the endotracheal tube are the main types of these injuries, in which local ischemia leads to neuropraxia. (26) It occurs because the myelin sheath of the nerve is damaged.

Retraction must be applied less than 175 minutes and relieved intermittently. (27) The compression of the RLN segment within the endolarynx as a result of retraction has been shown to cause of RLN injury. (28) Some surgeons prefer the use of hand-held retractors where the pressure can be controlled. (18)

7. Risk factors

Surgeries which required more extensive dissection increases the chances of a postoperative RLN injury. (29–31) The cadaver model supporting stretch neuropraxia, stretch was significant only retractor opening exceed 3 cm. (1) The opening of the retractor is limited by the placement of its blades under the longus colli muscle but preoperative evaluation should be made against the possibility of anatomical variation.

These parameters frequently were accepted as other risk factors: re-operations (revision surgeries), the right-sided surgery and endotracheal cuff pressures (ETCPs). (23,24,29,30,32,33)

First parameter was the re-operation. There was a significant increase in the rate of injury with reoperative anterior fusion. (29) Also in systematic review by Tan et al. revision procedures showed significantly an increased risk of RLN palsy. (34) In a prospective study, laryngoscopic examinations were performed before revision of ACDF patients and 17.3% (4 of 23) of patients had abnormalities. (35) Another study found that of 47 patients who underwent screening before revision ACDF, 13 (26%) had laryngeal abnormalities, including 11 cases (22%) with vocal cord paresis, of which 5 were asymptomatic. They also concluded that preoperative laryngoscopic examination should become a standard part of the preoperative examination of patients undergoing ACDF revision. (36)

Previous studies have suggested that a right-sided approach may predispose to RLN palsy because of the shorter, more oblique course of the right RLN. (23,37,38) An anatomical cadaver study comparing left-sided and right-sided approaches showed that an average stretching of the RLN of 24% occurred with right-sided approach. (1) However, the majority of right-handed spine surgeons performing ACDF prefer a right-sided approach. On the contrary; some studies showed that there was no association between the side of approach and the incidence of RLN symptoms. (29,39) Moreover in Gokaslan et al. study 79% of RLN palsy were approached from the left side. (40)

ETCPs and their effects on the injury mechanism of the right RLN were described by Apfelbaum et al. (30) Endotracheal tube may cause nerve ischemia by exerting pressure on the RLN and submucosal surface. (41) The compression of the intralaryngeal segment of the RLN within the endolarynx as a result of impingement has been shown to cause of RLN injury in ACSS. (28) Thats why the authors suggest to release of pressure after retractor placement to allow the endotracheal tube to re-center within the larynx. Diminishing the ETCP to 20 mm Hg after neck retractor insertion is recommended to avoid complications to visceral organs and nerves. (7,42) During anterior cervical access, the esophagus is pinched between the unyielding cervical retractors and the endotracheal tube. Lowered cuff pressure decreases compression of the esophagus. (43) In contrast to this information, another prospective study concluded that deflation/reflation of the endotracheal tube cuff did not reduce the incidence of RLN injury in ACDF. (42)

8. Preventive measures

In a study using direct laryngoscopy in patients undergoing ACSS, the authors found that the incidence of asymptomatic and symptomatic RLN paresis was 24.2%, with 15.9% of their patients developing clinically silent RLN paresis after surgery. (7) They stated only one third of RLN palsy could be detected without laryngoscopy. Especially in patients with previous ACSS, thyroid surgery, neck dissection, previous radiation therapy, and hoarseness or other symptoms suggestive of nerve palsy, indirect laryngoscopy should be performed preoperatively to assess the condition of the vocal cords. If the vocal cords are not functional on the side of the previous surgery, it is better to approach the cervical spine from the same side during revision surgery.

In another study of the use of intraoperative laryngeal EMG to predict the development of RLN palsy in 298 patients undergoing ACDF, the authors found significant laryngeal activity in 14.4% of patients, of whom 2.3% developed RLN palsy. (44) Routine use of intraoperative laryngeal EMG in patients undergoing ACDF procedures is not yet cost-effective.

9. Management

Although dysphonia is not uncommon after ACSS, it is transient in most patients. (45) Even RLN neuropraxia is a reversible condition, and full vocal cord movement is restored in a large number of patients within 12 months after surgery. Therefore, recovery can be observed in most patients without the need for extensive diagnostic testing. (46) Gokaslan et al. conducted a multicenter retrospective study on the RLN palsy after ACSS, and 75% of the patients in their study had complete resolution of symptoms. (40) The reported rate of persistent (> 12 months) symptomatic vocal fold paresis varies from 0.33 to 2.5%. (30,37)

Postoperatively, ice packs may be placed on the surgical site to limit bleeding and edema. A short course of steroids will speed recovery. The patient must be reassured that the problem is benign. Evaluation by a speech pathologist is useful to initiate compensatory mechanisms and voice therapy.

Surgical intervention is very rarely required. It is usually performed in patients who develop aspiration pneumonia or in whom the risk of aspiration precludes oral feeding. Injection laryngoplasty and medialization thyroplasty are used to treat permanent vocal cord paralysis. (23,47)

10. Conclusion

Currently, ACDF is the most commonly performed surgical procedure for cervical disc herniation with excellent results and relatively low complication rates. The incidence of RLN palsy in literature was underreported because of some surgeons accept it as minor symptom, short duration of this symptom or even asymptomatic mostly. Nonetheless, to understand the close relationship between the RLN and cervical fascia, a surgical cadaveric anatomic study of the anterior cervical region will help prevent RLN injury.

11. Abbreviations

ALL: Anterior longitudinal ligament
ACDF: Anterior cervical discectomy and fusion
ACSS: Anterior cervical spine surgery
ETCPs: Endotracheal cuff pressures
PLL: Posterior longitudinal ligament
RLN: Recurrent laryngeal nerve
SCM: Sternocleidomastoid muscle
SLN: Superior laryngeal nerve

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CHAPTER VI

VERTEBROPLASTY COMPLICATIONS

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The incidence of osteoporotic or neoplastic vertebral fractures continues to increase every day due to the increase in the world population and the increase in the elderly population in society. The pain that occurs after fractures negatively influences the lives of patients. Although conservative treatment methods can be used for treating these fractures, surgical methods also have an important place in the treatment. Percutaneous vertebroplasty is a minimally invasive surgical method frequently used for treating osteoporotic, traumatic, or neoplastic vertebral fractures (1). It is also used for treating painful vertebral hemangiomas (2).

Percutaneous vertebroplasty is a surgical method performed under sedation in the prone position, assisted with a scope. After making a 1-cm skin incision under the scope, the relevant vertebral corpus is entered transpedicularly or extrapedicularly with appropriate surgical instruments from one or both sides. The cannulated hand instruments in the vertebroplasty set are advanced to the relevant vertebral body. After confirming the cannula position with anteroposterior and lateral views under the scope, a viscous bone cement (polymethylmethacrylate) is injected into the vertebral body. The amount of cement injected may vary depending on the level of the relevant vertebra and the condition of the fracture. After the injection of sufficient cement, the cannulas are removed and the process is completed. Although percutaneous vertebroplasty is a minimally invasive surgical method, its complication rates are high, but these complications are rarely clinically evident.

Cement leakage is one of the leading complications of vertebroplasty. It can occur in the paravertebral soft tissues, veins, spinal canal, intervertebral disk space, foraminal space, or epidural space. Systemic complications of vertebroplasty are less common and include postoperative infection, fat embolism, and pulmonary embolism. New fractures in adjacent segments are also considered as a complication of vertebroplasty. Rib fractures due to surgical technique are also among the complications of vertebroplasty.

In this section, the complications of the percutaneous vertebroplasty procedure were discussed.

Pain

After the vertebroplasty procedure, a temporary increase in pain may occur in the patient. This pain, which is thought to be due to the inflammation caused by the heat generated during the polymerization of polymethylmethacrylate injected into the vertebral body, can be controlled with simple painkillers and resolves within a few hours (3).

Transient Arterial Hypotension

Although the cause of transient arterial hypotension, which has been reported as a rare complication, has not been fully elucidated, it is clinical hypotension that occurs during polymethylmethacrylate injection and improves in the short term with supportive treatment (4).

Cement Leakage

It is the most common complication of vertebroplasty. In a study by Lee et al., patients were evaluated with post-procedure tomography, and it was reported that 87.5% of the cement leaks out of the corpus occurred after the procedure (5). Computed tomography is the gold standard in demonstrating cement leakage. Cement leakage is generally caused by the injection of low-viscosity cement (6). Certain publications have reported that the amount of leakage increases as the volume of injected cement increases (7).

The appropriate amount has been reported as 3.5 mL in the thoracic spine and 4 mL in the lumbar spine (8).

It has been reported that low-viscosity cement injection increases the risk of leaking, while high-viscosity cement reduces this risk (9). On the contrary, animal experiments have shown that the pressure increase that occurs during the injection of high-viscosity cement increases the risk of oil embolism (10). To prevent these complications, it is argued that bone cement should be applied when it does not fall with its own weight in the area where it comes into contact with the air at the tip of the needle (11).

Cement Leakage into Disk Space

It is a condition in which viscous cement injected into the vertebral body leaks into the adjacent intervertebral disk space. Cement leaking into the intervertebral disk space is thought to increase the risk of fracture in adjacent vertebral bodies (12).

To prevent this situation, it is recommended to work carefully under the scope, place the cannulated cement injector more lateral to the corpus, and use it when the viscosity of the cement is denser. It has been shown that the use of less cement reduces this risk (12,13,14).

Cement Leakage into the Epidural Space or Foraminal Space

Epidural or foraminal cement leaking, which is a rare complication, can be seen in 40% of cases, but cannot be detected because it does not cause clinical signs in most patients. It is detected in patients undergoing computed tomography (CT) imaging after surgery (14,15). Cement leakage into the foraminal space may cause foraminal stenosis-like symptoms but may also cause severe radicular pain. In patients who develop unexpected radicular symptoms after the procedure, the cement leakage into the foraminal space may need to be surgically removed after CT control.

Cement Leakage into Paravertebral Veins

The clinical situation that causes serious complications of vertebroplasty is the leakage of viscous cement into the paravertebral veins, causing pulmonary embolism, cardiac perforation, cerebral embolism, and death. This may be caused by the use of cement with high viscosity, or it may occur in the vertebroplasty procedure applied to hypervascular lesions (14).

Pulmonary cement embolism occurs at a rate of 4.6% after vertebroplasty, and this situation is usually asymptomatic (16). Symptomatic pulmonary embolism has been reported as 1.1% (17). Chest pain, hypotension, and shortness of breath occur in symptomatic patients. Oxygen therapy, anticoagulant therapy, and intravenous steroid therapy should be started immediately. This clinical condition may result in sudden death (18).

Cardiac perforation is also an extremely rare complication of vertebroplasty (19,20). It mostly results in death by causing hemopericardium and tamponade.

Cerebral embolism occurs as a result of fat embolism due to increased intramedullary pressure during vertebroplasty.

New Fracture Formation in Adjacent Spine

In patients undergoing vertebroplasty after osteoporotic vertebral compression fracture, the risk of fracture formation in the vertebrae adjacent to the vertebroplasty-applied vertebrae is higher than that in other vertebrae. This is thought to be due to the increased rigidity of the vertebroplasty-applied spine. The probability of fracture in the adjacent spine was found to be 4.6 times higher in some studies (21). In a meta-analysis, the probability of fracture in the adjacent segments was found to be 54.6% (22).

The degree of osteoporosis in the patient and the kyphotic deformity of the spine are important risk factors for new fracture formation. The leakage of cement into the intervertebral disk space during vertebroplasty may increase the risk of fracture (23).

Infection

Infection, a complication seen in percutaneous interventions, is not just a complication of percutaneous vertebroplasty treatment. The infection rate after vertebroplasty has been reported as 1% (24). Diabetes and urinary tract infections are the most important risk factors in the patient. Possible consequences of infection are discitis, osteomyelitis, and epidural infection. The infection can be mild, or it can cause serious conditions that require advanced surgical treatments. The most frequently isolated microorganisms are *Staphylococcus aureus* and *Mycobacterium tuberculosis*.

It is recommended to use prophylactic third-generation cephalosporins or to add tobramycin into bone cement to prevent infection (25).

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CHAPTER VII

CERVICAL LAMINOPLASTY COMPLICATIONS

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INTRODUCTION

Cervical myelopathy is the clinical condition that occurs after the cervical spinal cord is compressed due to dorsal and/or ventral lesions. It is more common in the elderly population due to degenerative and spondylotic causes. It may also occur at an earlier age in those with congenital spinal canal stenosis (1).

Cervical laminoplasty was first described in a study by Oyama et al. in 1973 as a surgical option for treating cervical myelopathy in patients with ossified posterior longitudinal ligament (OPLL) (2). Cervical laminoplasty is a posterior approach in which the spinal canal width is increased by preserving the dorsal elements to eliminate spinal cord compression. Preservation of the posterior elements during surgical treatment helps prevent complications such as kyphosis and instability. Since cervical laminoplasty allows the posterior migration of the spinal column, it also indirectly causes anterior decompression.

Laminoplasty is a method that does not affect mobility to a large extent, does not carry the risk of pseudoarthrosis, and offers the possibility of indirect anterior decompression. Some studies have shown that laminoplasty has better clinical results and less complication rates than laminectomy in correctly selected patients (3,4).

Compared with laminectomy, laminoplasty allows physiological loads due to the protection of posterior structures and produces results much closer to natural biomechanics. The preservation of the posterior elements after laminoplasty and the formation of the postlaminectomy membrane around the dura provide surgical advantages if revision surgery is needed(5).

Liu et al. reported no difference in Japanese Orthopedic Association (JOA) scores between patients who had only laminoplasty and those who had anterior cervical discectomy and fusion. However, they demonstrated a serious loss of neck movements in patients who underwent anterior surgery (6).

Seng et al. showed no difference in JOA and Visual Analog Scale (VAS) scores between the group undergoing laminoplasty and the group that had anterior discectomy and fusion, but the complication rates were higher in the anterior surgery group (7).

Cervical Laminectomy Indications

- Cervical myelopathy or myeloradiculopathy due to OPLL
- Congenital narrow canal
- Multilevel disk herniations
- Traumatic central cord syndrome

Laminoplasty is the first line of treatment for patients with multilevel cervical myelopathy without (or minimal) axial neck pain and normal lordotic alignment.

Since laminoplasty is a surgical approach that does not involve fusion, it is not indicated for treating spondylotic neck pain. Fusion surgeries should be preferred in patients with axial neck pain complaints. The aim of laminoplasty surgery is to decompress the spinal cord. Anterior surgery or foraminotomy is a more appropriate option in patients with isolated signs of radiculopathy.

Contraindications

The presence of cervical kyphosis (>10–15 degrees) is a relative contraindication because it may cause insufficient decompression. Suda et al. reported poor results in patients with a local kyphosis angle of more than 13 degrees without magnetic resonance changes and in patients with a local kyphosis angle of more than 5 degrees and myelopathy findings accompanied by MR changes (8).

Studies comparing laminectomy and posterior fusion with laminoplasty showed no significant differences in functional scores and clinical findings between patients who underwent laminectomy and fusion and those who underwent laminoplasty. However, less lordosis loss was observed in patients who underwent laminectomy and fusion. In these studies, laminectomy and fusion method were recommended as surgical options in patients with C2–C7 kyphosis angle greater than 10–15 degrees (9,10).

Inflammatory arthritis such as ankylosing spondylitis and rheumatoid arthritis are among the relative contraindications (11). However, with appropriate medical treatment, laminoplasty can be applied in selected cases in these diseases (12).

Types of Laminoplasty

Open-Door Laminoplasty

In the open-door laminoplasty technique described by Hirabayashi et al. (13) in 1978, a complete osteotomy is performed at the junction of the lamina and facet on the symptomatic side. The hinge point is created on the opposite side and the lamina is removed on the hinge point, increasing the channel diameter. Suturing techniques, bone block grafting, or plate fixation techniques can be used to preserve lamina patency.

Reclosing the opened door is a complication of this technique. The complication rates vary according to the fixation method used while applying the technique.French-Door Laminoplasty

It is a technique defined by Kurokawa et al. in 1982 (14). It is a technique in which the spinous process is separated from the middle with the help of a burr and the spinal canal is widened from the posterior by opening the laminas laterally from the hinge points formed at the lamina–facet junction on both sides. It requires the use of bone blocks to keep the opened door open.

Problems may occur in the spinal canal during the separation of the spinous process from the posterior into two equal parts in the compressed epidural area. In addition, the bone block to be used to preserve the opening leads to donor site problems.

LAMINOPLASTY COMPLICATIONS

Surgical Wound Problems

More wound problems are encountered in posterior cervical approaches compared with anterior approaches. The wound site problems are between 5% and 8% (1,15).

Good pre-closure bleeding control, use of subcutaneous drains, and proper closure of the wound layers are important steps in preventing this complication. Similarly, the use of topical vancomycin is an effective method to prevent problems such as wound infection (16).

C5 Palsy

A relatively common complication of cervical laminoplasty is C5 nerve palsy. It can be seen with a rate of 4.8% in patients who underwent cervical laminoplasty, and this is the lowest complication rate among all cervical decompression surgery methods (17). It is thought to be due to the tension in the roots emerging from the ventral aspect of the posteriorly migrated spinal cord after laminoplasty. Although 50% of the patients who develop C5 palsy experience motor problems in the deltoid muscle and/or biceps brachii muscle, 50% have sensory and motor problems in the C5 dermatome. Most palsy occurs in the first week after surgery and is usually unilateral. C5 palsy resolves spontaneously within months. Imagama et al. revealed that 67% of patients who developed C5 palsy showed complete recovery in the first 4 months. They stated that the patients who did not show a full recovery were those with preoperative deficits (18). It has been reported in the literature that unilateral or bilateral foraminotomy should be combined with laminoplasty in patients with preoperative root compression findings to avoid serious complications of C5 palsy (2).

Axial Neck Pain

Axial neck pain is another complication seen after cervical laminoplasty. The cause of this pain is facet damage or muscle dissection. Hosono et al. showed that patients who underwent only anterior surgery for cervical narrow canal had much less neck pain than those who only underwent laminopalsty (19).

Preservation of the semispinalis cervix has been shown to reduce axial symptoms after surgery. In traditional C3–C7 laminoplasty, the semispinalis cervix muscle is stripped from the C2 spinous process during C3 laminoplasty and then re-fixed. Some authors recommend C3 laminectomy and C4–C7 laminoplasty for preserving the semispinalis cervix muscle. Takeuchi et al. obtained better axial neck pain scores in patients who underwent C3 laminectomy and C4–C7 laminoplasty than in patients who underwent traditional C3–C7 laminoplasty (20). Mesfin et al. also showed that the protection of the semispinalis cervix muscle reduced the occurrence of axial neck pain (21).

As mentioned earlier, the surgical treatment option for treating axial neck pain is fusion instead of laminoplasty. Laminoplasty does not worsen axial neck pain in patients who do not have severe axial neck pain in the preoperative period, have a smooth sagittal alignment, and have a correct surgical technique. It provides an improvement in clinical problems caused by myelopathy (22).

Loss of Movement

Although laminoplasty is a surgical procedure that preserves mobility, it may cause some limitations of movement. This may be due to interlaminar fusion between adjacent segments whose laminae are opened, damaged posterior cervical extensor muscles, and/or the use of an extended neck collar.

C2–C3 interlaminar fusion develops in 28%–88% of patients who underwent laminoplasty (23,24).

Loss of Lordosis

The change in lordosis loss in the direction of kyphosis after laminoplasty is a surgical technique–dependent complication. Preservation of the attachment sites of the muscles is extremely important for preserving the sagittal cervical alignment. During the posterior cervical approach, care should be taken to dissect the avascular planes between the paraspinal muscles. In the surgical approach, the surgeon should avoid pulling the lateral structures too much laterally. This may result in increased spondylolysis, axial neck pain, and loss of lordosis due to facet capsule damage.

The semispinalis cervicis and capitis muscles act as dynamic stabilizers on the cervical spine. Applying laminectomy to C3 instead of laminoplasty ensures the preservation of the attachment sites of the muscles in the C2 vertebra and is effective in preserving the cervical sagittal alignment. In patients who were planned for C3–C7 posterior decompression due to cervical myelopathy, 9 degrees of lordosis loss occurred in those who underwent C3–C7 laminoplasty, while only 3 degrees of lordosis loss occurred in patients who underwent C3 laminectomy and C4–C7 laminoplasty (25). Similarly, Takeshita showed that preserving the C2 muscle attachment sites prevented the loss of lordosis (26).

Preoperative sagittal alignment also affects surgical results. Suk et al. showed that the preoperative lordosis angle of less than 10 degrees and the development of cervical kyphosis during flexion were factors affecting the formation of postoperative kyphosis. In addition, Matsuoka et al. reported that cervical kyphosis development was more common in patients with increased lumbar lordosis and decreased pelvic incidence–lumbar lordosis measurement (28).

Neurological Worsening

Traumatic spinal cord injury is an extremely rare complication with serious consequences. Worsening after decompression has also been reported, though rarely, in patients without intraoperative spinal cord injury. This is thought to be due to free radicals formed in the reperfusion cycle after decompression (29).

Recurrent Stenosis

The incidence of recurrent stenosis has been reported as around 10%. It occurs most frequently at C5–C6 levels (30). This complication has been observed with the use of suture or bone graft techniques to keep the lamina open.

CONCLUSIONS

Cervical laminoplasty is the best treatment option for patients with multilevel stenosis and cervical myelopathy with smooth sagittal alignment and minimal axial neck pain. To avoid the complications of laminoplasty, care should be taken to protect the attachment sites of the semispinalis cervicis muscle. Damages that may occur in this muscle cause postoperative pain, loss of anatomical alignment, and decrease in neck movements. Before spinal surgery, the entire spinal column should be evaluated in detail in terms of sagittal balance.

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CHAPTER VIII

PEDICLE SCREW-RELATED COMPLICATIONS IN THORACOLUMBAR AND LUMBOSACRAL SPINE SURGERY

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1. Pedicle Screw History

Pedicle screw fixation is considered to be the gold standard of spinal internal fixation because of its many advantages in treating a variety of deteriorating spinal conditions. Pedicle screws provide a means of gripping over a vertebral segment and limiting its motion. The screws themselves don't fixate the spinal segment but act as strong anchor points that can then be connected with a rod. Posterior instrumentation systems prevent motions in the segments that are being fused. Pedicle screws are put in the pedicles of the successive vertebra, then a rod is placed to connect the screws. Posterior segmental arthrodesis is performed using autograft or allograft during the operation. In posterolateral fusion, the use of pedicle screws has improved spinal fusion rates by approximately 60% to 90%. Vertebral screw fixation history starts in the 1940s. Since its first introduction in the 1940s, vertebral and pedicle screw fixation has continued to evolve and increase its popularity among spine surgeons. Tourney and King were the first to declare the use of bone screws to obtain internal spinal fixation at the time of fusion in 1943 and 1944, respectively. Boucher and Pennel described a method of placing longer machined stainless steel screws through the facet joints as a method of internal fixation in 1959 and 1964, respectively. Screws were usually placed into the pedicle and vertebral body below, through the inferior facet. Using pedicle screw systems for spinal stabilization has become increasingly widespread in spine surgery. (1) Harrington and Tullos were the first to place pedicle screws through the isthmus of the pedicle. (2) Buck described the use of screw fixation for direct repair of isthmic lytic defects with 16 patients with spondylolisthesis in 1970 for the first time. (3) Roy-Camille, under the supervision of Judet, defined the use of sagittally positioned posterior plates with screws through the pedicles and articular process. (4) Louis and Maresca changed their technique before several authors did the same, which resulted in trans-pedicular screws being altered to be used in different cases. (5,6) Major advances in the last two decades have emerged in the surgical instrumentation of the vertebral column. A midline lumbosacral plate hooked onto the spinous processes and fixed with trans-pedicular screws was described by Cabot. (7) Pedicle screws are medical implants that are implanted posteriorly to the vertebrae of the spine and attached to a longitudinal rod to create a structure that corrects spinal alignment or supports stabilization. Thoracolumbar and lumbosacral pedicle screw instrumentation for achieving rigid fixation of the spine is a well-demonstrated technique used for numerous spinal disorders. Pedicle screw instrumentation is technically demanding and possesses the risk of perioperative and postoperative complications. Trans-pedicular screw fixation has been used frequently in spinal surgery due to its unique biomechanical properties compared to different spinal fixation techniques. (8) Identification of the anatomical landmarks of the posterior arch of the vertebra is the principal basis of pedicular screw insertion. Ideally, the maximum diameter and length of a pedicle screw should ensure that the integrity of the cortical layer of the pedicle or the vertebral body is not breached. (3,9) For the localization of the pedicle and assurement in the placement of the screw in the desired position, fluoroscopic guidance is utilised. (7) Rigid fixation with enhanced segmental control is guaranteed by pedicle screws.

Compared to no pedicle fixation devices, pedicle fixation offers better restoration of the spinal sagittal contour and makes a shorter fusion feasible. Besides making a shorter fusion feasible and a more reliable fixation in osteoporotic patients who underwent previous laminectomies. (10) Frequent clinical and biomechanical usage of pedicle screws caused improvement in their design, leading them to have an easier application with minimal implant failure rates. Even though pedicle screws had the improvements mentioned, it is still a challenging technique possessing risk, even performed by experienced surgeons because of being near neural and vascular components. (11,12)

2. Pedicle Definition

The pedicle is a stub of bone that connects the lamina to the vertebral body to form the vertebral arch. The pedicle extends bone that connects the lamina to the vertebral corpus forming the vertebral arc. Pedicle is a sturdy cylindrical anatomic bridge between vertebral body and dorsal spinal elements. It comprises a strong shell of cortical bone and alveolar bone at the core. Each vertebra has two pedicles sticking out from the vertebral corpus that provides protection on either side for the spinal cord and nerves. They are also a bridge connecting the posterior and anterior components of the vertebrae. Pedicles are short, round, bony processes extending backwards from the vertebral body. They connect the lamina and the vertebral body. Nerves leave the spinal column and pass underneath the pedicle through exit holes called foramina. The pedicles are two short processes, which project dorsally, one on either side, from the superior part of the vertebral body at the junction of its posterior and lateral surfaces. They connect the body of the spinal vertebra to the arch. (Figure 1 and Figure 2)

Figure 1: Vertebrae Anatomy

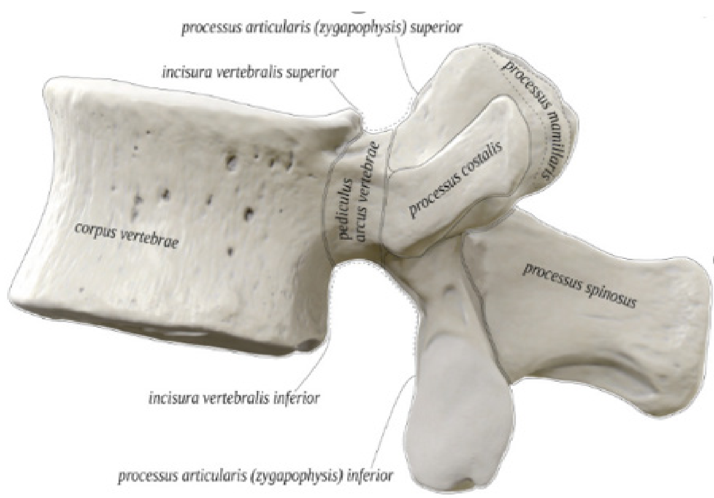


Figure 2:Vertebrae Anatomy Anterior and Lateral Position

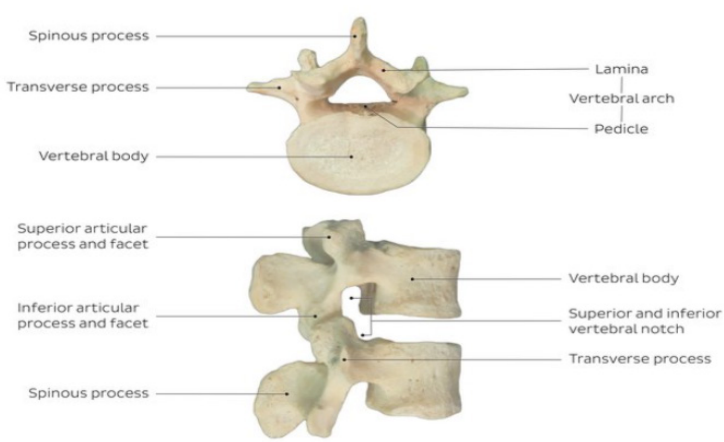
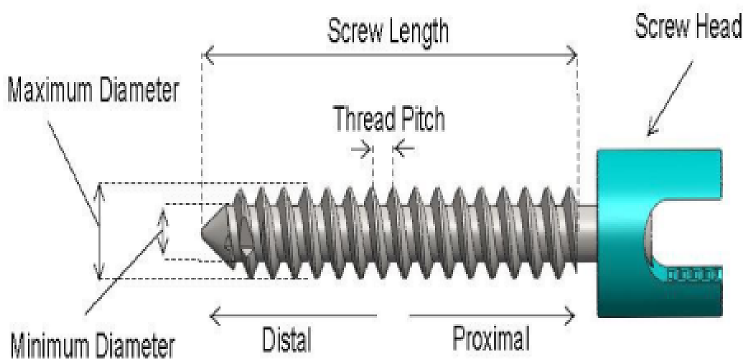


Figure 3:The components of the pedicle screw (13)



3. Pedicle Screw Indications

Lumbar Spondylolisthesis
Thoracolumbar trauma
Post-Laminectomy Instability
Lumbar canal stenosis and degeneration
Recurrent disc herniation
Spondylolysis
Neoplasm
Infection
Scoliosis and malformations

4. Pedicle Screw Placement

Pedicle screws can be inserted by free hand. In addition, fluoroscopic, navigation-guided and robot-assisted pedicle screw placement can be performed. Various cautions should be considered. Free-hand placement malposition, which can lead to loosened screws and nerve injuries, the rate is 1%-10%. (14-15) Image navigation techniques based on CT and fluoroscopy may lead to longer operation times, more radiation exposure and a greater risk of infections. (16) Various techniques can be used during pedicle screw placement, and different outcomes may occur. (17-18) The most important landmarks are the transverse process and facet joints.

Complications were grouped into three categories.

5. General Complications

5.1 Infection
5.2 Deep Vein Thrombose and Pulmonary Embolism.
5.3 Vascular injury (Excessive bleeding)
5.4 Visceral Injury
5.5 Chest infection
5.6 Ileus
5.7 Donor graft pain

6. Neurological Complications

Spinal cord injury
Paraparesis or Paraplegia
Radicular injury,
Neural ischemia
Radicular pain, or Dural tear and CSF leakage

7. Pedicle Screw-Related Complications

7.1 Pedicle fractures
7.2 Screw Pullout
7.3 Screw or Rod Breakage
7.4 Screw Malposition,
7.5 Rod Fracture
7.6 System Failure and loss of correction
7.7 Pedicle screw loosening

The rates of general complications are 13.8%, neurological complications are 8.3%, and pedicle screw-related complications are 18.5%.

5. General Complications

5.1. Infection

Surgical area infection in the spine is a serious postoperative complication. The frequency of infection varies according to the surgery performed, the implant used, and the risk factors. The incidence of postoperative infection has been reported to be between 0% and 20%. (19) Fusion applied with spinal instrumentation causes a slight increase in the infection rate and in retrospective studies, this rate is between 2.1-8.5% (20,21). Wound site infection is relatively high in cases of spinal surgery with instrumentation. Recognition of potential factors that may lead to infection can reduce the risk of surgical wounds. The following measures can be taken to reduce the risk of surgical infection.

Use of prophylactic antibiotics

Pre-operative bathing with antiseptic soaps, shaving off the skin,

Maintaining clean skin,

Adequate hand washing,

Using double gloves,

Attention to sterilization during surgery,

Asing laminar airflow in the operating room

Keeping doors closed and reducing operating room traffic,

Keeping the surgical time short

Cheng et al. found that in spinal operations, washing the surgical site with the povidone-iodine solution before the closure procedure reduces the risk of infection. The povidone-iodine solution shows bactericidal activity against many pathogens including methicillin-resistant staphylococcus aureus (22) 1st generation cephalosporins are the most effective antibiotic group against staphylococcal strains and administration 20 minutes before surgery ensures sufficient concentration in tissues. The infection rate after spinal surgery with instrumentation is 0.1-13%. Routine use of prophylactic antibiotics reduces the infection rate to 6%. (23)

The frequency of infections after surgical interventions on the spine can be summarized as follows.

After İdiopathic scoliosis surgery 0.1-5 %

After lumbar fusion, 3-5% (24)

After fusion with posterior instrumentation, 26% (25)

After thoracolumbar fracture fusion, 9.4-15% (26)

Adding fusion to surgical methods, performing more dissections, increase in the amount of blood loss, and prolonging the operation time cause an increase in the frequency of infection. The incidence of surgical infection because of inadequate sterile covering of the microscope increases.

Risk Factors For Postoperative Spine Infections

Medical risk factors

Cardiovascular disease

Diabetes Mellitus

Chronic steroid use

Advanced age (> 60)
Trauma
Immunodeficiency,
Nutritional disorders
Cigarettes, alcohol
Previous infections,
Urinary infection
Pregnancy
Malignant disease
Neuromuscular disease
Prolongation of hospital stay
Obesity

Surgical Risk Factors

Prolongation of the operation time
Increased blood loss
multiple levels joining the fusion.
Creation of Dead Space
Revision surgery
Excessive number of personnel in the operating room
Allograft use
Prolongation of hospital stay

Exceeding 5 hours of operation time increases the risk of infection. (27)

In the study, Fang et al., advanced age, smoking, alcohol, diabetes and previous infections were evaluated as statistically significant risk factors. (28) Wimmer et al. reported that the amount of blood loss was over 1000 ml in 19 of 22 patients with postoperative spine infection. (29) Malnutrition increases the risk of postoperative infection. Enteral and parenteral nutrition must be provided before elective surgical operations. Jensen et al. determined that there is a nutrition deficiency in patients with serum albümin levels below 3.5 mg/dl, total lymphocyte count below 1500 cells/ml, serum zinc levels below 670mg/dl, or serum transferrin level below 150 g/dl. They suggested postponing the surgery and providing nutritional support. If the patient is obese, the decision for performing surgery should be made after the patient loses enough weight. Infection-related complications occur in obese patients through several mechanisms. It occurs due to decreased vascularity and immune response in the adipose tissue, leading to fat necrosis and a suitable environment for the growth of bacteria. (30) Smoking is a risk factor for infection. In elective surgeries, it should be ensured that the patient quits smoking. Immunocompromised patients receiving chemotherapy or chronic steroid use are at risk for postoperative spine infections. In addition, the risk of infection is increased in systemic diseases such as diabetes, malignancy and AIDS. Postoperative complications occur in approximately 17% of diabetic patients, and approximately two-thirds of these have an infection. Diabetes-related hypertension, renal failure, and cardiovascular diseases increase the risk of soft tissue infections. (31) The risk of infection decreases significantly in surgeries performed after the blood glucose level is controlled. (32) Prolonged hospital stay leads to colonization of bacterial agents, increasing the risk of infection. Increased risk of infection in patients with myelodysplasia, cerebral palsy and paralytic scoliosis. Infection is observed in two ways, according to its anatomical location, superficial and deep. Superficial infections are limited to the skin and subcutaneous tissue and are typically caused by bacteria on the skin. Necrosis and infection increase because of insufficient circulation in the superficial region, the pressure effect of the retractor, and the damage of electrocautery. Deep infection is located under the fascia. Insufficient blood circulation in deep spinal tissues, such as postoperative local tissue necrosis, haematomas, and intervertebral disc are optimal environments for infections. Infection due to dural injury may progress to the cerebrospinal fluid and meninges. (33) The most common cause of infection after spine operations (60%) is coagulase-negative staphylococcus aureus. (34) Other microorganisms are staff epidermidis, gram-negative bacteria, propionibacterium acne, group B streptococci, Enterobacter cloacae escherichia coli proteus mirabilis, enterococcus faecalis, pseudomonas aeruginosa, klebsiella pneumonia, acinetobacter baumanni, providences settler. Escherichia coli and Enterococcus faecalis cause wound contamination from the genitourinary or faecal route in patients who underwent spinal instrumentation operations. The most common microorganisms causing infections found in patients using intravenous treatments are staphylococcus aureus and pseudomonas aeruginosa. Microorganisms form a glycoprotein biofilm layer on the metal parts of the implants, restricting the defence mechanisms of the organism. In many cases, there is an infection with more than one organism. The early infection develops within the first 3 months and is due to contamination during surgery. It can be caused by the patient's skin flora, surgical team, instruments or operating room air. Late infections develop within 6 months to 2 years and occur with haematogenous spread.

Diagnosis

Pain is often the first symptom of infection. In the early stages of infection, erythema, oedema, local tenderness and usual drainage are seen around the wound. A mild fever is seen in most patients. Back and lower back pain, fistula causing spontaneous drainage of the skin, can be seen as a sign of late infections. Pullter Gunne et al. showed that in patients who underwent spinal instrumentation, wound drainage was 67.9% in deep infection and 64.6% in superficial infection. (35) The increase in WBC, sedimentation and CRP with increasing fever should suggest infection after spinal instrumentation. Postoperative CRP levels increase initially and return to normal within 2 weeks. (36) Postoperative ESR peaks at two weeks and returns to normal levels in six weeks. Khan et al. followed the CRP and erythrocyte sedimentation levels in the follow-up of 21 patients with early infection after spinal surgery. They reported that while the response to intravenous antibiotic treatment led to a rapid improvement in CRP values, sedimentation values returned to normal later and CRP was superior in evaluating the response to infection treatment. (37)

5.2. Deep Vein Thrombosis and Pulmonary Embolism.

Deep vein thrombosis (DVT) and pulmonary embolism (PE) are life-threatening complications. A meta-analysis of elective spine surgeries because of degenerative causes was calculated at a DVT rate of 1.4%. (38) This rate rises to 10% in patients undergoing single-level posterior lumbar interbody fusion when examined using venous duplex ultrasonography. (39) Intraoperative blood loss, combined anterior and posterior surgical procedures, prolongation of the operation time and immobilization increase the incidence of DVT. (40,41) Patients aged 60 and above, (Body mass index) BMI>30, history of DVT or pulmonary embolism, hormone replacement therapy, use of oral contraceptives, presence of active malignancy, presence of kidney disease increase the risk of DVT in the postoperative period. (42) Stopping smoking 1 year before surgery reduces the risk of DVT. Duplex ultrasonography is useful for the clinical diagnosis of DVT. Duplex ultrasonography is safe, efficient, noninvasive, and relatively inexpensive, but it is insufficient for the accurate assessment of intrapelvic veins. To reduce the risk of deep vein thrombosis, patients should be dressed in compression stockings or elastic bandages on the legs before surgery. Venous stasis should be prevented throughout the operation with an intermittent leg compression device (sequential compression device, SCD). In the treatment of patients with deep vein thrombosis, low molecular weight heparin, unfractionated heparin, early mobilization, and anti-embolism stockings are recommended.

5.3 Vascular Injury

Several vascular structures are in danger of injury during the insertion of the pedicle screw: the azygos vein, intercostal artery, inferior vena cava, and aorta for the thoracic spine and mainly the aorta and common iliac vessels for the lumbar spine. A sudden drop in blood pressure and accompanying tachycardia should suggest a vascular injury. Primary suture or embolisation should be performed on the injured vessel. Some authors consider revision procedures too risky. Foxx et al. found that 33 of 680 screws contact the greater vessels of the thoracolumbar region, none were symptomatic and none caused complications. (43) Some other authors have recommended revision because the screw contacting the pulsating vessel may cause laceration or pseudoaneurysm.

5.4 Visceral Injury

The proximity of thoracolumbar vertebral bodies to internal organs may explain visceral organ injuries. Complications of some visceral organs have been observed in the literature. A pedicle screw that is too long in the thoracic region might damage the oesophagus, pleura, and lung. O›Brien et al. determined that the pedicle screw tightens the oesophagus at the T3 vertebra level. In esophagoscopy, areas showing weakness in the mucosa were observed, but no perforation was detected. The authors replaced the pedicle screws at T3-T5 levels with bilaterally short ones.

6. Neurological Complications

There is a risk of neurological complications in patients after spinal arthrodesis. (44) Permanent neurological deficits are rare, although temporary neurapraxia is a common complication. One of the most serious complications of scoliosis correction surgery is iatrogenic spinal cord injury. (26,27) The incidence of neurological complications for spinal deformity surgery has been reported as less than 1% by the Scoliosis Research Society. The overall incidence of a nerve root or spinal cord injury is rare, ranging between 0.6% and 11%. (47) In a study by Pihlajamaki et al., they found a permanent drop of foot in 3 out of 102 patients. İt was found that the screw was misplaced in only 1 of these cases. (48) If a new neurologic deficit or pain occurs postoperatively, revision should be performed by showing malposition of the screws. Planning should be done by drawing a target that includes the pedicle. The use of navigation and CT scanning is recommended during pedicular screwing. Thoracic pedicle screw-based instrumentation consistently achieves significant results in fixation and deformity correction, therefore it is the most used technique in the treatment of scoliosis. (49,50) Thoracic pedicle screw fixation is potentially risky because of the little space between the spinal cord and the medial wall of the pedicle. The incidence of screw-related neurologic complications ranges from 0 to 0.9 % during the treatment of spinal deformities surgery with thoracic pedicle screws. The incidence of screw misplacement increased by up to 43% when all the screws were evaluated by computed tomography (CT) after scoliosis surgery. (51,52) Postoperative new neurological deficit or a new pain requires careful evaluation of postoperative images to rule out a malposition of the screw, in which case surgical revision is necessary. The planning of the revision procedure should be complete and precise. A new trajectory within the pedicle should be planned. During the procedure, the misplaced screw must be exposed and correctly positioned. In such cases, the application of intraoperative navigation or CT scanning is suggested. Most dural lesions are seen during decompression of the neural canal, rather than screw insertion. Dural lesions have been reported with a mean incidence of 0.18% per pedicle screw. Di Silvestre et al. reported dural injuries in 14 cases (12.2% of patients); all were asymptomatic. (53) Dural tear should be repaired during the operation, it should be sutured as watertight and using tissue adhesives. Nakashima et al. reported that they successfully treated dural CSF leakage after pedicle screw insertion using fibrin glue. (54) Malposition of a pedicle screw (for example) is a commonly reported complication in literature, with an incidence of 0%-42%. (55) In the presence of preoperative kyphosis, the probability of developing a neurological deficit after surgery increases 22 times. (56)

7. Pedicle Screw-Related Complications

7.1 Pedicle Fracture

Complications of malpositioned screws can lead to nerve root irritation, pedicle fractures, vascular injuries, CSF leaks and visceral injuries. The pedicle screw breakage rate has been reported for lumbar fusion operations as 1.1% in the literature. (57) Pedicle fractures that developed during the operation were reported by 3 authorities. (52,53,58) This occurs because of a miscalculation of pedicle size and screw diameter. To prevent this complication, pedicle diameter, pedicle angle, and screw length should be planned preoperatively. Tapping before screw insertion is recommended in young patients because it is a hard, cancellous bone. To prevent pedicle fracture, it should be suitable for the screw hole with the diameter of the inserted screw. The surgeon should choose an alternative method for fixation when pedicle fracture develops.

7.2 Screw Pullout

Screw pullout is because of the loss of metal-bone interface integrity. Screw loosening in spinal fusion surgery is a clinical complication in patients with poor bone quality. The factors affecting the pullout strength of pedicle screws are osteoporosis, excessive strain on the implant, screw hole preparation technique, the torque of insertion, screw purchase, and direction of screw placement. Pullout strength can be done to increase by sub-laminar hooks or tapping the screw hole. Restoring sagittal balance is necessary to prevent a new screw pullout.

7.2 Screw Breakage

Screws, plates, rods, and other types of spine surgery equipment are made of powerful materials. (for example, titanium or composites) Screw breakage can occur for various reasons after the operation. In one study, the frequency of screw breakage was between 0.5% and 11.2% of the inserted screws. Lonstein et al. found 3 factories related to screw breakage. These factors are the design of the screw, pseudoarthrosis and their use in burst fractures. (59)

Figure 4

Figure 5

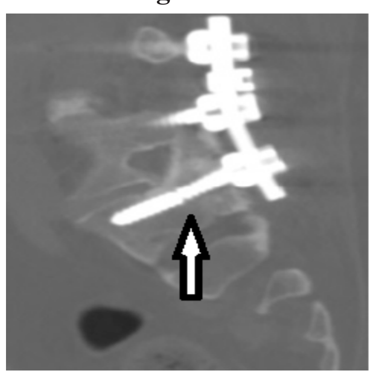
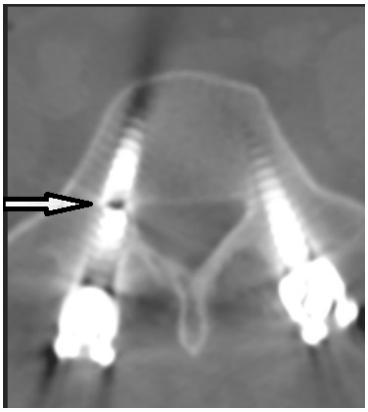


Figure 6



7.3 Screw Malposition

Malposition is defined anatomically by the relationship of the screw with the pedicle and the corresponding vertebral body. (58) Pedicle screws have been used in spinal surgery for a long time. Despite the many techniques developed for screw placement today, screw misplacement continues to occur**.** They were found by Hicks et al. In 21 literature reviews, the rate of screw malposition for scoliosis surgery in the radiographic examination is 11%. However, this rate increased to 15.7% in studies using computed tomography (CT) after surgery. (57) Malpositioned screws can lead to relevant complications, such as nerve root irritation, pedicle fracture, vascular injury, cerebrospinal fluid leak, and visceral injury. (60-62)

7.4 Rod Fracture

The incidence of symptomatic rod fracture following adult spinal deformity surgery was reported as 6.8% by Smith et al. (63) Another study by Smith et al. rod fracture averaged 14.7 months following adult spinal deformity. If pedicle subtraction osteotomy was added to surgery, rod fractures developed in 22% of the patients in their 1-year follow-up. (64) The incidence of rod breakage has increased in patients who underwent non-fusion surgery because of spinal deformity. Rod fractures are significantly associated with age, high body mass index, previous surgery, and pedicle subtraction osteotomy. Also, a factor is the small diameter of the rod. Rod fractures increase after multilevel spinal correction operations. Arthrodesis must be added to posterior spinal instrumentation to reduce rod breakage.

Figure 7

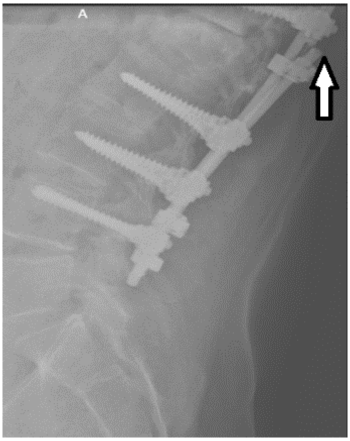


Figure 8

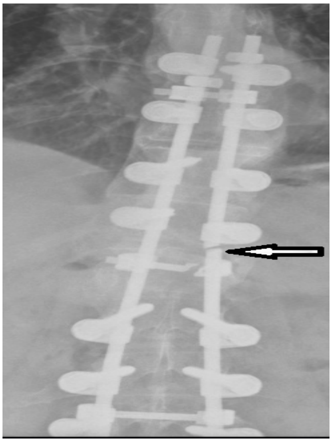
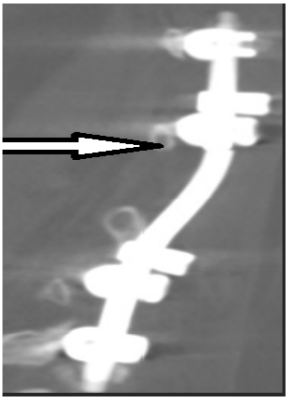


Figure 9



8. Conclusion

The procedure is necessary to reduce the complications associated with the pedicle screw; to experienced spine surgeons, quality spine instruments, and comprehensive preoperative assessments.

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CHAPTER IX

VENTRICULOPERITONEAL SHUNT COMPLICATIONS

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1. Introduction

To fully and accurately evaluate ventriculoperitoneal shunt complications, we must first understand what hydrocephalus is, its types, mechanism, and cerebrospinal fluid (CSF) physiology.

2. What is Hydrocephalus

Hydrocephalus is of Latin origin and derived from two different words: hydro: water, cephalus: head, and watery head. Hydrocephalus is a sudden or chronic neurological disease that occurs due to cerebrospinal fluid (CSF) accumulation in the ventricles more than the normal levels. The definition of hydrocephalus was first made by Severino. (1) Hydrocephalus is the second most common congenital brain malformation. (2) It can occur in any period of life, starting from intrauterine life. A sudden increase in pressure due to intracranial pressure increase syndrome (ICP) can cause serious brain damage, including life-threatening, developmental and mental problems. CSF is made up to 500 ml daily and absorbed at the same rate. Its main task is to protect neural tissues, equalize pressure, transport neurotransmitters and suspension. As a result of the imbalance in CSF production and absorption, it expands due to its accumulation in the ventricles and leads to hydrocephalus. In general, hydrocephalus develops in three ways.

1-Increase in CSF production
2-Obstruction in the CSF circulation pathways
3-Disorders of venous drainage and absorption

Excess CSF production mostly occurs in choroid plexus papillomas. (3) CSF circulation pathways; These may be obstructed in the subarachnoid space or the ventricular system. If the obstruction occurs in the ventricular system, it is called non-communicated hydrocephalus, and if there is an obstruction in the subarachnoid space, it is called "communicated hydrocephalus". (4) In communicating hydrocephalus, there is an excess of CSF production or a problem in its absorption, there is no obstruction in the CSF circulation pathways. Radiologically, there is an image of tetraventricular hydrocephalus due to enlargement in all ventricles.

CSF pressure is high in all ventricles. The underlying cause of the overproduction of CSF may be choroid plexus tumours or hyperplasia. When the causes of CSF absorption disorder are examined, there are reasons such as previous meningitis, subarachnoid haemorrhages, arachnoiditis, leptomeningeal fibrosis and arachnoid villus obliteration. Obstruction occurs due to the deterioration of the relationship between the ventricles in non-communicating hydrocephalus. There are differences in pressure before and after obstruction. Aqueduct stenosis, congenital Atresia of Foramen Monro, Arnold–Chiari, Dandy-Walker malformations, space-occupying tumoral structures, congenital disorders such as meningomyelocele, cysts, haemorrhages and skull base anomalies can be listed as the conditions causing obstructions. Impairments in venous drainage cause hydrocephalus due to increased pressure in arachnoid granulations and impaired absorption. (5) There are cases of normal pressure hydrocephalus, which are usually seen over 60 years of age. In 1965, Hakim and Adams first described it using the Normal Pressure Hydrocephalus (NPH) entity. When we look at the known classic tirade of NPH, it is impaired cognitive functions such as dementia, urinary incontinence and impaired gait in varying degrees. CSF pressure of the patients is normal and ventricular dilatation is seen. It was determined that the findings improved as a result of the evacuation of CSF by lumbar puncture from the patients. In NPH, gait is first impaired and this is symmetrical. With small steps and a wide base, a slowdown in walking speed is observed. Subcortical and frontal cognitive functions are affected. The presence of ventriculomegaly at a higher rate than atrophy in the sulci in brain MRI helps the diagnosis. Evans index greater than 0.30 supports the diagnosis. Improvement of the patient's gait after unloading lumbar deterioration in CSF circulation and absorption. In these patients, motor and mental dysfunctions are observed over time due to the chronic event. (8)

2.1. Cerebrospinal Fluid (CSF) Physiology

CSF is a colourless, odourless and clear liquid that circulates between the ventricular system and the subarachnoid space. It acts as a natural cushion and suspension for the brain. CSF provides the circulation of various substrates, metabolic products, hormones and neurotransmitters formed as a result of brain metabolism. In addition, it protects the brain against mechanical trauma by acting as a regulation in the inner part of the central nervous system. It has many functions such as preventing direct contact of the brain with the extracellular region. Most of the CSF production is produced by the choroid plexus in the lateral ventricles. CSF production rate is 350 μl/min. CSF produced in the lateral ventricles reaches the 3rd ventricle via the foramen of Monroe and then to the 4th ventricle via the aqueduct Sylvius. It reaches the subarachnoid space via the Foramen Magendie and foramina of Luschka. CSF comes up to the interpeduncular cistern via the prepontine cistern and from there to the brain convexity via the chiasmatic cistern. CSF, which circulates over the cerebellar hemispheres, reaches convexity again through the quadrigeminal cistern, ambient cistern, and vena cerebri magna cistern. CSF also passes into the spinal cord's central canal and spinal subarachnoid space. Absorption occurs from the arachnoid villi to the venous sinuses. Arachnoid villi are composed of cells extending from the subarachnoid space to the sinus lumen. The arachnoid villi are covered by the endothelial layer, which has tight junctions with the inner layer of the sinus wall. This structure acts as a one-sided valve that passively absorbs CSF in the direction of the pressure gradient. If the CSF pressure is lower than the venous pressure, the arachnoid villi close and prevent the blood from passing into the ventricular system. Part of the CSF passes into the perineural space through the ependymal layer lining the ventricles, the choroid plexus, and the spinal subarachnoid space. A very small part of the CSF drains into the nasal submucosa and then into the cervical lymph nodes via the cribriform plate and arachnoid villi on the olfactory nerves. However, the amount of CSF drained in this way is extremely low. Ventriculoperitoneal shunt systems are one of the most common and effective methods used in the treatment of hydrocephalus today. (9,10) In addition, endoscopic third ventriculostomy is performed in appropriate cases. Although the most commonly used ventriculoperitoneal shunt systems, it is rarely used in ventriculoatrial and ventriculopleural shunt systems. In the presence of hydrocephalus, the proximal end of the shunt is placed in the ventricles and connected with a pump with a different pressure gradient that prevents excessive discharge under the scalp. The shunt catheter, which is passed under the skin of the chest and abdomen after the pump, is then placed in the pleural area in the abdomen.

Looking at the historical process, Jan Mikulicz Radecki was reported to be the first researcher to perform the ventricular CSF diversion procedure in 1893. (11,12) Towards the end of the 19th century, materials made of catgut and gold tubes were used as ventricular-subdural shunts. (13-15)

The first recorded ventricular-subcutaneous shunt procedure was performed in 1903 by Nicolas Senn using a perforated rubber tube. (12-14) It was used by Kausch in 1908 for the suction of CSF from the peritoneal cavity with a ventriculoperitoneal shunt (VPS). (16) Arne Torkildsen used a rubber catheter in 1939 to divert CSF from the lateral ventricles to the cisterna magna in cases of aqueductal obstruction. The Torkildsen shunt is the most notable pre predecessor of a modern CSF shunt. This shunt procedure (ventriculocisternostomy) has been shown to have good long-term patency rates. (17)

In 1947, Franc D. Ingraham published the safety of using a synthetic polymer, polyethene, as a ventricular catheter to explore possibilities for using better biomaterials to guide ventricular CSF.(18)

The modern treatment of hydrocephalus began in 1949 when surgeons Frank Nulsen and Eugene Spitz demonstrated that shunts that carry cerebrospinal fluid to the blood vessels were effective in reducing pressure in the ventricles. These surgeons used rubber tubes to shunt the CSF.(19,20) Many different biomaterials have been used to date. However, polyethene is an inadequate shunt material and it has been frequently observed that ventriculoperitoneal shunt systems have blockade at the distal end of the omentum or bowel. (21) In 1957, he used poly dimethyl silicon (PDMS) or silicone for ventriculoatrial shunts. (22) Silicone rubber became a widely used permanent medical device material in the 1940s and 50s due to its excellent bio-inertness and flexibility. (13) Richard Ames placed the first silicone ventriculoperitoneal shunt system in 1958 and published a promising report of 120 cases. (15) Medical-grade silicone has become an extremely popular material for shunts.

3. Ventriculoperitoneal Shunt Complications

Ventriculoperitoneal shunt (VPS) placement is one of the most commonly performed neurosurgical procedures and is required to treat many forms of hydrocephalus. Shunt dysfunction is recognized as the most common neurosurgical complication encountered. (23)

Shunt surgery is a common neurosurgical procedure, which is performed for approximately 30,000 times per year in the United States. (24) Complications punctures, and reduction of incontinence helps determine the group that will benefit from ventriculoperitoneal shunt surgery.

In the studies conducted, the prevalence of congenital hydrocephalus in Europe and the United States was calculated as 0.5–0.8/1000 live births. (6,7) Ventricular diameter in newborns is associated with 2 factors. The first is the level of myelination of the brain. Since myelination in the newborn brain is not fully completed, the brain parenchyma has a soft and flexible structure. Because of this, the ventricles can easily expand. In addition, another factor is the flexible structure of the skull bones. These factors allow the growth and flexibility of the brain in newborns, and the ventricles can easily expand. Hydrocephalus may develop acutely or may occur in a chronic process. A sudden obstruction in the ventricular system can lead to acute hydrocephalus within hours. If the cranial sutures are closed, the patient becomes unconscious, clinically deteriorates and cerebral herniation may occur. Symptoms such as headache, nausea and vomiting are the first signs to appear. In hydrocephalus developing in the chronic process, it is seen due to the related to VPS insertion are extremely common and multiple shunt revisions are expected during a patient's lifetime. Shunt dysfunction can be attributed to many causes, including obstruction, infection, pseudocyst formation, and intestinal perforation.

The most common VPS obstruction occurs in the proximal end of the catheter. The second most common cause of VPS failure is infection, and it is a frequent complication in premature infants who are the most susceptible. Despite continued attempts to reduce the incidence of VPS complications, such as advanced sterile techniques, antibiotic-impregnated catheters, and programmable valves, it remains a major problem resulting in costly hospitalizations. VPS failure rates have been estimated to be approximately 11-25% within the first year after initial shunt placement. (25,26) Many sources have shown that the rate of shunt revision is higher among pediatric patients than in adults. Although VPS placement is a common neurosurgical procedure, complication rates in adults range from 17 to 33%. (27-29)

At 5 years, children had a higher rate of shunt complications than adults (48% vs. 27%). (30)

Complications of ventriculoperitoneal shunt cover a wide spectrum, and the classification can be classified as mechanical or non-mechanical causes, or it can also be made according to the complications that develop in the localization of the shunt. Mechanical complications include obstruction, shunt disconnection, and migration. Non-mechanical complications include infection and complications related to the distal compartment (pseudocyst formation, ascites, and pleural effusion). (31-32)

4. Problems with Proximal Catheter and Reservoir

Reservoir exit

Misplacement of the Ventricular Catheter

Shunt Migration

Breakage of the catheter

Occlusion of the catheter

Shunt Infections: Wound infection, Ventriculitis, Meningitis

Scalp necrosis

CSF collection around the reservoir and catheter

Effusion due to CSF overdrainage, chronic subdural hematoma

Intraparenchymal haemorrhage in ventricular catheter tracing

Headache, drowsiness, nausea, vomiting, vision changes due to partial or complete obstruction of the shunt

Slit ventricle due to overwork of shunt

5. roblems Associated with Distal Catheter

The shunt coming out of the skin during its course under the skin of the chest and abdomen and infection

CSF collection along the distal tube

Breakage of the catheter

Catheter protruding from the anus

Obstruction associated with pseudocyst

Cerebrospinal fluid acid

Abdominal pain

Bowel perforation

Placement of the shunt outside the peritoneal space

Hydrocele

4. Problems with Proximal Catheter and Reservoir

Between 19-33% of patients undergoing ventriculoperitoneal shunts, shunt revision was observed within 6-12 months after surgery.

4.1 Reservoir Exit and Ventricular Catheter Misplacement

The main reason for the reservoir to come out is that it is not sufficiently fixed under the skin. In addition, it is the result of tension due to the incompatibility of ventricular catheter direction and distal catheter direction. In pediatric patients, weak subcutaneous tissue may also be a factor.

Ventricular catheter (VC) misplacement has been defined as the presence of the VC tip in the contralateral ventricle or intraparenchymal area (Kakarla grades 2-3). (33) Today, brain tomography is routinely performed in the early postoperative period for the early detection of this complication. Ventricular catheter (VC) misplacement occurs in 36-60% of cases and is a common cause of shunt revision. (28,30,34) It may cause proximal shunt obstruction due to misplacement of the ventricular catheter (VC) tip into the parenchyma, and may also cause neurological impairment, vascular injury and increased risk of intracerebral haemorrhage. (35-37) Many surgeons apply the (VC) tip with the free-hand technique, targeting the tip ipsilaterally to the anterior part of the lateral ventricle. (38,39) Although retrospective studies have found that a correctly placed VC tip reduces proximal shunt dysfunction, no difference was found in the overall shunt revision rate. (40) Wilson et al. reported that the failure rates were reduced as a result of their studies compared to the free-hand technique using stereotactic neuronavigation or ultrasound. (41) In patients with more pronounced ventriculomegaly, the risk of VC misplacement and intracerebral haemorrhage decreases.

4.2 Shunt Migration

Shunt migration, which is one of the mechanical complications, is roughly stated in 1 out of 1000 patients who underwent the shunt procedure. It is relatively rare compared to other shunt-related complications (such as infection or shunt obstruction). Migration can be defined as the displacement of part or all of the shunt system (proximal/distal catheter/reservoir/valve) from the required compartment to a new compartment. This may or may not be related to shunt dysfunction.

Types of shunt migration

A-Location of migration

Intracranial, subgaleal, breast, thorax, abdominal wall and genitourinary organs,

B-Direction of migration

Cranial or caudal

Migrating parts in the C-Shunt system; proximal catheter, distal catheter, valve, reservoir, the whole shunt system

In general, migration to the caudal direction is more common than cranial. Caudal migrations are usually asymptomatic, while cranial migrations are usually symptomatic. (42) The incidence of caudal migration is around 10%. (43) Shunt migrations can also be classified according to their clinical presentation.

Symptomatic: shunt dysfunction, shunt infection

Asymptomatic

It was determined that 14% of the migrations were to the scrotal and 4% to the bladder and perineum. Abdominal wall migration may occur to anterior, posterior, or umbilical areas. Until 2016, 40 of 57 patients had migration to the anterior abdominal wall in the shunt tube, transumbilical migration was detected in 10, and migration to the posterior abdominal wall was found in 7 patients. The largest case series is Abode-Iyamah et al. 16 patients were reported in 2016. (44) The use of laparoscopy for distal catheter placement to prevent shunt migration to the abdominal wall has been suggested to reduce migration. (45.46) The incidence of intracranial and subgaleal migration constitutes 0.1-0.4% of total shunt complications. (47) Intracranial migration includes migration to the ventricle, brain parenchyma, and subdural space.

Migration to the thoracic cavity is observed at a rate of approximately 8%. The first patient with distal catheter migration into the thoracic cavity was reported in a 14-month-old child in 1977 by Obrador et al. (48) Taub and Lavyne in 1994 classified the complications of VPS related to thoracic shunt as follows;

A- Lung damage or pneumothorax as a result of intraoperative trauma while placing the shunt,

B- Pleural effusion associated with CSF acids and pleural effusion due to catheter migration into the thoracic cavity can be counted as tension hydrothorax, pneumonia, and broncho-pleural fistula. (49) Migration into the chest cavity may cause acute or chronic respiratory distress in approximately 78.8% of patients due to pathology, and shunt dysfunction or infection in 15.1%

of patients. Following placement of a ventriculoperitoneal shunt, migration into the chest cavity occurs between 5 days and 16 years after the last surgery. (mean duration: 33.6 months; median duration: 5 months). (50)

The cardiac and Intravascular migration rate is (7%). The earliest migration to the heart was reported by Morell et al in 1994 in a 12-year-old child. (51) Chest CT scan, echocardiography, and CT angiography may be recommended to confirm the diagnosis of migration to the heart.

Migration to the breast tissue is seen at a rate of about 3%. Breast-related complications include CSF pseudooxygen, shunt migration, and shunt occlusion. Among these, shunt migration is the most common complication. (52)

4.3 V-P Shunt Infection

Ventriculoperitoneal shunts (VPS) drain increased cerebrospinal fluid (CSF) from the cerebral ventricles, usually into the peritoneal cavity. Shunt systems have significantly reduced the morbidity and mortality rates associated with hydrocephalus. Shunt infection is a common complication of shunt surgery. Most shunt infections occur within 3 months of shunt surgery. Shunt infection is a common complication ranging from 5.6% to 12.9% (60). In pediatric age, shunt infections cause shunt dysfunction, increasing treatment costs due to shunt revision, neurodevelopmental delay, and prolonged hospital stay. In the treatment of infection after shunt surgery, a common protocol has not yet been achieved in the world. Antibiotic treatment alone is insufficient, and treatment with surgical intervention is recommended. (61) The risk of shunt infection is negatively associated with age, and the risk is increased in premature babies. The risk of shunt infection is increased, especially in those who have hemorrhagic hydrocephalus, a history of shunt infection in the past, CSF leakage, and those who were operated with neuroendoscopy. (62) The most common etiological factors of shunt infection in patients were reported as congenital anomalies. Spina bifida patients with hydrocephalus are the most common. (63) Shunt infections are classified as early shunt infections within the first six months and later as late shunt infections.

Infection with biofilm-forming bacteria can be complicated. The most common microorganisms causing VPS infection are coagulase-negative staphylococci originating from the skin flora. It can also cause infections in gram-negative microorganisms and fungi. (64) Biofilm-forming bacteria such as Staphylococcus epidermidis and Staphylococcus aureus cause shunt infections by adhering to the surface of the shunt system. Shunt infection is generally defined as the isolation of a bacterial pathogen from CSF by both gram staining and culture with CSF pleocytosis. In this case, the patient presents with fever, neurological symptoms, and signs of shunt dysfunction. Shunt infections; It leads to increased shunt revision rates, recurrences of infection, wound infection, ventriculitis, meningitis, encephalitis, and peritonitis, often leading to higher mortality rates. (65)

It may be beneficial to take some precautions to reduce the risk of infection before and during the operation. Simple measures such as hand washing and reducing the bacterial load on the patient's skin, wearing or changing gloves during surgery, and minimizing contact with the shunt have proven to be effective and efficient techniques against shunt infections. (66) There are differences in the management of shunt infections among centres. Combined methods including temporary removal of the shunt, and then application of external ventricular drainage (EVD), intraventricular anti-biotherapy as well as systemic antibiotics are applied. (62) The administration of perioperative antibiotics may help reduce the risk of infection, but the optimal antibiotic is not clear, but vancomycin is the most commonly used for this purpose. Kestle et al. evaluated a surgical protocol that included the use of intraventricular antibiotics during surgery to overcome the pharmacokinetic limitations of perioperative antibiotics to reduce shunt infections, resulting in a reduction in infection rates, but were unable to detect a reduction specifically attributable to intraventricular antibiotics. Its use in antibiotic-impregnated shunts such as rifampicin or clindamycin for the prevention of infection has been studied. (67)

4.4 Subdural Hematoma After Ventriculoperitoneal Shunt

There is a risk of developing subdural hematoma (SDH) in 2-17% of patients with ventriculoperitoneal shunts. (68) As a result of shrinkage in the brain parenchyma due to excessive CSF drainage, it causes stretching of the bridging veins in the subdural space and makes it prone to bleeding even after minor traumas. Factors causing SDH in VPS patients include the valve type of the shunt system and the use of antiplatelet drugs or anticoagulants. (69.70)

Subdural hematoma (SDH) or hygroma is considered one of the most common complications in patients undergoing shunt due to idiopathic normal pressure hydrocephalus (INPH). (71) Subdural hematoma can be asymptomatic on brain CT, or it can lead to conditions ranging from mass effect to hemiparesis and coma. The risk of developing SDH in patients with iNPH after shunt surgery is associated with physiological characteristics such as brain compliance, ventricular size, and drainage capacity of the shunt. (72) Low-pressure shunts predispose patients to excessive drainage, increasing the risk of subdural hygroma and hematoma.

4.5 Slit Ventricular Syndrome (SVS)

SVS is a rare syndrome seen in 3-5% of patients with a VP shunt. (73) Slit ventricular syndrome is a complication that occurs after years of excessive CSF drainage of the shunt in patients with ventricular shunt placed in infancy. SVS symptoms usually appear 2-5 years after shunt placement. The mean time between hydrocephalus and diagnosis of SVS is 4.3 years. (84) Peak incidence is between 4-6 years of age. Babies with a small head circumference (below the 25% percentile) are at increased risk. (74) SVS may be associated with skull growth disorders such as secondary craniosynostosis. (75) SVS can also occur in adults after ventriculoperitoneal shunt placement. The disease is characterized by severe headaches that impair the quality of life in patients with normal or undersized ventricles. The pathogenesis of SVS is not fully understood. Many theories have been mentioned in the literature. (7) Excessive drainage of CSF may cause ventricular collapse, resulting in intermittent shunt obstruction and cerebral hypotension. Slit ventricles can be seen on computed tomography (CT) imaging. As a result of chronic over-drainage of CSF, it may cause proximal obstruction of the ventricles and subsequently collapse, causing reactive subependymal gliosis. Craniocephalic disproportion occurs when the volume of the brain and the skull grow disproportionately. Patients with SVS may suffer from an under-functioning shunt or an overworking shunt; may develop intracranial hypertension or hypotension in case of excessive drainage. Hallmark reported that SVS symptoms may include headache, nausea, vomiting and mental status changes, but some patients may be asymptomatic. The clinical condition may be compatible with shunt dysfunction or shunt overdrainage. Headaches are typically in episodes lasting 10-15 minutes. Vital sign changes such as vomiting, hyperventilation, bradycardia, and hypertension may be present. (76) Complications of SVS include subdural hematoma, hypotension, and intracerebral haemorrhage. In patients with shunt disorders, vision loss due to papilledema or diplopia may occur as a result of 6th cranial nerve paralysis due to increased intracranial pressure. It can be difficult to treat. Initially, the replacement of an adjustable shunt valve with an anti-siphon feature can be attempted. If severe symptoms persist, then revision with a more appropriate pressure shunt should be performed.

5.1 Cerebral Shunt Dysfunction Or Shunt Obstruction

Shunt dysfunction is the failure of the cerebral shunt, resulting in partial or complete occlusion of the shunt causing intermittent or no operation. When a blockage occurs, cerebrospinal fluid (CSF) builds up and can cause the symptoms of untreated hydrocephalus. A shunt occlusion from blood cells, tissue, or bacteria may occur anywhere in the shunt. Both the ventricular catheter (the part of the tube inserted into the brain) and the distal portion of the catheter can be blocked by tissue. Shunts are very durable, but due to wear or as the child grows, their components can snap or break. Sometimes they come out from where they were originally placed. The fracture causes a complete or partial interruption in the shunt path that can impede fluid flow and add resistance to the system. A rupture may occur, but the formation of scar tissue around the subcutaneous catheter may allow fluid to drain. Migration may also alter the shunt function, causing the catheter to move to places that may restrict its flow. Rarely, a valve system may fail due to a mechanical failure. Intracerebral and intraventricular haemorrhage due to ventriculoperitoneal shunt is a rare complication and usually occurs immediately after surgery. (53) Asymptomatic, small parenchymal haemorrhages around the ventricular catheter can sometimes be seen on postoperative computed tomography. Sayers reported six cases of intracerebral hematoma among 1390 cases of shunts. Ivan et al described one case of thalamic haemorrhage among 243 cases. According to these reports, the risk of intracerebral hematoma is between 0.4% and 3.6%. Although the incidence of complications is low, the mortality is high and can reach from 50% to 100%. (54-55)

5.2 CSF Collection Around Reservoir and Catheter

In adults, edematous fluid collection along the intracranial tract of the ventriculoperitoneal shunt catheter is rare but is more common in children. (56.57) Bianchi et al. reported a case of per catheter cyst mimicking a cystic tumour in 1 patient. The motor deficit was detected in the patient who had a VP shunt catheter inserted due to hydrocephalus due to myelomeningocele. In the surgical observation of this case, no continuity was observed after the ventricular exit of the ventricular catheter. (58) Amans and Dillon reported a case of a per catheter cyst around a VP shunt catheter placed for the treatment of hydrocephalus. (59) The exact aetiology of per catheter collections is still unclear despite all studies. In the presence of a per catheter collection, shunt dysfunction rather than infection or tumour should be considered. The findings are due to the accumulation of CSF in the brain parenchyma as a result of the pressure difference between the intraventricular CSF and the brain parenchyma. It is more common in children because the brain parenchyma is more flexible to pressure.

5.3 Abdominal Pseudocyst

An abdominal pseudocyst is a rare complication after VP Shunt and may cause shunt dysfunction or abdominal symptoms and signs. The presence of infection, previous abdominal surgery and repeated shunt revisions are predisposing factors. A pseudocyst may develop due to poor or non-absorption of CSF from the abdominal serosa. Intracystic pressure increases over time and prevents the optimal function of the shunt. When we look at the clinical findings, include signs of shunt dysfunction such as abdominal pain, tenderness, abdominal bloating, nausea or vomiting, decreased appetite, constipation, fever, lethargy, and headache, with or without a palpable mass. It may turn into focal peritonitis or low-grade infection due to inflammatory reactions in the cyst wall. (77) When in doubt, it should be confirmed by imaging followed by excision of the cyst and repositioning of the shunt.

5.4 Hydrocele

As a complication of migration or extrusion of the peritoneal end of the V-P shunt, CSF may accumulate in the scrotum and rarely lead to hydrocele. Extrusion into the scrotum is extremely rare and only occurs in newborn babies during the first year of life. Premature infants seem likely to develop this complication due to a residual patent processus vaginalis (PPV). PPV occurs in approximately 50-60% of 1-month-old infants. The presence of PPV may predispose to the migration of VPS to the scrotum. Placement of a ventriculoperitoneal shunt may cause an increase in intra-abdominal pressure and may lead to hydrocele as a result of migration in the presence of prolonged PPV. Fernandez-Ibieta et al. inserted a ventriculoperitoneal shunt in a total of 295 patients over 40 years and reported 7 (2.3%) cases in which the ventricular tip migrated to the scrotum via PPV. In addition, cases with inguinal hernia did not show shunt dysfunction; however, shunt dysfunction was found in cases with hydrocele. (78)

Conclusion

Today, ventriculoperitoneal shunt systems are still frequently used in the treatment of hydrocephalus. Acute hydrocephalus or dysfunction due to shunt complications can lead to a life-threatening conditions. It is of great importance that neurosurgeons dealing with hydrocephalus and shunt surgery have sufficient knowledge and experience about existing complications that may develop.

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CHAPTER X

SURGICAL COMPLICATIONS IN INTRACEREBRAL TUMORS

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1. Introduction

Complications can be defined as any deviation from the normal postoperative course within 30 days of an operation performed. Close monitoring and management of intracerebral tumors during and after surgery enables rapid detection of neurological deterioration and maintenance of systemic and neurological homeostasis.

Major complications occur at a rate of 13-27% after intracranial surgery (1). These may be neurological, hemodynamic, metabolic or respiratory complications. Major neurological complications include postoperative hematomas, cerebral edema, and seizures (2). Forgetting a foreign body and wrong-side surgery are rarer cases and reported incidences are less than 0.7 per 1000 cases. In particular, it has been reported that these cases do not carry an increased risk of mortality (3).

Landriel et al. proposed a four-grade scale based on a treatment used to treat cranial and spinal complications. Grade I covers any non-life-threatening complication treated without invasive procedures, while grade II covers complications requiring invasive treatment such as surgical, endoscopic, and endovascular procedures, grade III covers life-threatening adverse events requiring treatment in the intensive care unit, and grade IV covers deaths resulting from complications. In their study, they found 10.84% surgical and 3.19% medical complications. While the overall mortality rate was 1.17%, it was observed that 0.84% of the deaths were directly related to surgical procedures

(4). According to this proposed classification, iatrogenic strokes, hematoma, and meningitis were all considered surgical complications.

In a study of 16,530 patients who had undergone surgery for malignant brain tumors, Garza showed that the risk of at least one surgical complication was 3.4% (3).

Although the incidence of neurological and non-neurological complications in intracerebral tumor surgery varies, general complications are seen at rates between 9% and 40%. In intracerebral tumor surgery, neurological complications can be seen at the rates of 10%-22%, hemodynamic complications of 5%-14%, respiratory and metabolic complications of 3%-11%, and hemorrhagic complications of 0-3%. Overall mortality rates range from 1.5% to 16% (5-8). Bradycardia, hypertension and hypotension, myocardial ischemia can be considered among hemodynamic complications (9).

The rates of complications vary according to the type of tumor, its localization and the surgical methods applied. In intracerebral tumor surgery, complications can occur at the rates of 1% to 24% due to incomplete closure of the dura. Postoperative peritumoral edema has been reported at the rates of 2%-10%, early postoperative seizures of 1%-12%, medical complications of 6%-7%, wound infection of 0%-4%, and surgery-related hematoma and wrong site surgery of 1%-2% (10).

Measurements in large-scale studies have reported a 30-day readmission rate of 7.5% to 17.3% among patients undergoing surgical resection of a brain tumor. Seizures, surgical site infection, and new motor deficits are the most common causes of readmission (11,12).

It has been observed that regional and systemic complications are more common in patients over 60 years of age with preoperative Karnofsky Performance Scale scores of 50 or less (13).

2. Complications

2.1. Neurological complications

Neurological disorders are the most important complications of surgical resection (14). Neurological disorders occur in 10% to 22% of intracerebral tumor surgery. Neurological deficits that occur after intracerebral tumor resection vary according to the localization of the tumor (5,8). These can be grouped as newly developing motor deficits, dysphasia, seizures and clouding of consciousness (9).

In the study by Nanda on petroclival meningiomas, cranial neuropathy findings such as 3rd cranial nerve involvement and partial 7th cranial nerve involvement were detected in 44% of patients postoperatively with transpetrosal and orbitozygomatic interventions (15).

In a study of 1000 cases, the most common surgical complication was iatrogenic stroke, with an estimated incidence of 16.3%. It is observed that iatrogenic stroke also increases the risk of in-hospital death by 9 times. Gempt et al. analyzed the incidence of infarction following glioma resection (with diffusion-weighted imaging) and found new postoperative ischemic lesions with a reduction in neurological function in 31% of the patients included in their study. This group of authors defined the proximity of the tumor to the central arteries as the greatest risk factor for postoperative ischemic injury (16).

Today, it is seen that postoperative neurological functions are better preserved in surgical intervention combined with the use of intraoperative navigation, neuromonitoring, and developing imaging techniques such as magnetic resonance and computed tomography. Surgical experience also has an important effect on reducing neurological complications.

Recent reports suggest at least 70% resection and less than 5 ml residual tumor at most, especially in glial tumors (17). Considering that maximum resection of the tumor load plays an important role in the effectiveness of chemotherapy and radiotherapy treatments and in the follow-up period, it is inevitable that the surgeon will face the risk of neurologic deficit (18).

In a study conducted in 1998, the incidence of major complications was 13% and the operative mortality rate was 1.7% in 400 patients operated for intracerebral brain tumor. While the major neurological morbidity rate was 8.5%, 32% of these patients recovered and 58% showed no change. The locations of tumors affecting brain function were found to be the most important variable affecting the incidence of neurological deficits (13). For example, in a study on sphenoorbital meningiomas, 15% visual loss, 23% trigeminal hypoesthesia, and 7% oculamator palsy were reported (19).

Using intraoperative neuronavigation to avoid neurological complications in intracerebral tumor surgery may also provide significant benefit in maximal tumor resection. In terms of surgery, however, teamwork and specialization in this type of surgery play an active role in avoiding complications.

2.2. *Tumor recurrence*

Benign tumor recurrence is one of the most frequently reported events after surgery for intracranial tumors (10). Tumor recurrence in benign tumors largely depends on the localization of the tumor, its stage, and the surgical technique applied. For instance, tumor recurrence may be inevitable even in benign tumors in deeply located and difficult to reach cases or in cases with a vital structure in close proximity. Surgical experience and surgical intervention technique may also be effective in tumor recurrence. In a study by Nanda on petroclival meningiomas, the rate of patients with tumor recurrence and progression in an average of 84 months was reported as 12% (15). Tumor recurrence in sphenoorbital meningiomas was observed in 18% of cases in an average of 40.7 months. However, in convexity meningiomas, the recurrence rate has been reported as 2.9% in grade 0-1 tumors and 31% in stage III-IV tumors (20).

In glial tumors, radiotherapy and chemotherapy are administered to the patient until tumor recurrence is observed. Patients who are operated on for tumor recurrence survive significantly longer without a higher risk of complications than patients who do not undergo surgery (21). When reoperation is required due to tumor recurrence, preoperative anatomical landmarks become unclear due to tumor recurrence and gliosis, and adhesions may predispose patients to cerebral cortex injuries. Vascular nutrition in the skin, prior radiation, steroid use, and scar tissue may increase the risk of non-healing of the wound (22).

Although the complication rates seen in patients who underwent reoperation were higher, it is seen that there is no statistically significant difference between these rates and the complication rates seen in the first surgery in these patients (21,23,24).

Series including patients who underwent re-craniotomy for glioma resection have reported the total complication rate as 21.9%, and neurological complication rates between 7.7% and 48% (25,26).

In insular gliomas in the WHO grade II-IV index, 6.4% visual field defect and 2.1% hemiparesis were detected in patients who were reoperated due to tumor recurrence, and it was reported that no change was observed in the presence of a new postoperative deficit (27).

2.3. Intracerebral bleeding

Patients with hypertension, taking antiplatelet and anticoagulation drugs, and those with thrombocytopenia are at greater risk of bleeding after craniotomy. Headache due to decreased Glasgow scale, increased intracranial pressure, vomiting, worsening of consciousness, and anisocoria are common symptoms in these patients. Hypertension may cause postoperative hematoma (2). Acute physiological changes during recovery from anesthesia, sympathetic activation, increase in cerebral blood flow and intracranial pressure, tremor, and cough may be responsible for intracranial complications (1).

Complications that develop according to the location of the intracerebral tumor give clues about what we may encounter during and after the operation. For example, in a study performed on supratentorial tumors, the most common postoperative complication was bleeding with a rate of 40%, while the most common complication in posterior fossa and intraventricular tumors was hydrocephalus with a rate of 37.5%-40% (28).

Right supratentorial intracerebral hemorrhage after posterior fossa craniectomy to remove medulloblastoma is a rare complication. However, it has unfortunately been associated with high morbidity and mortality rates (29).

Postoperative distant intracranial hemorrhage secondary to craniotomy surgery is an extremely rare but fatal complication. In a study by Xu, where 9 patients out of 4588 patients who underwent brain tumor surgery had postoperative distant hemorrage, distant epidural hematoma in 6 cases, distant subdural hematoma in 2 cases and distant cerebellar hematoma in 1 case were reported. A total of 7 patients with severe neurological condition or massive hematoma were operated for hematoma (30).

Postoperative hemorrhage, which is a rare complication after cranial operation, can result in prolonged postoperative hospital stay, severe neurological impairment and even death. Wang et al. reported that postoperative hemorrhage requiring surgery occurred at a rate of 1.8% after intracranial tumor resection in 2259 adult patients who underwent primary surgical resection of a single intracranial tumor. They identified advanced age, higher INR, and larger tumor size after intracranial tumor resection in adults as independent risk factors for postoperative hemorrhage (31).

The reported 30-day mortality rate after brain tumor surgery is 2.2% to 2.9%, and the most common cause of mortality is postoperative hematoma. Kageji et al. reported hematoma requiring reoperation in 2.09% of 1149 patients who were operated for intracranial tumors. Mortality was observed in 12.5% of these patients within 30 days after the first surgery, and it was significantly associated with hemorrhages requiring repeat surgery, hemangioblastoma, infratentorial tumors, and prolonged operation time of more than 10 hours. It was reported that the clinical condition at discharge was worsened in 52% of the patients (32).

Similar to iatrogenic strokes, intracerebral hemorrhage significantly increases the risk of in-hospital mortality. Tanaka et al. found the incidence of intracerebral hemorrhage, which was mortal following surgical intervention, with a rate of 5.6% (33).

Jacobo et al. reported that poor prognosis may occur in patients who need refractory decompression secondary to intracerebral hemorrhage after resection of the intracranial tumor (34).

2.4. Brain edema

Postoperative cerebral edema is a common complication in patients with high-grade glioma after craniotomy. Both computed tomography and magnetic resonance imaging are used to diagnose cerebral edema (35).

Cerebral edema results from leakage of plasma from the vessel wall into the parenchyma due to disruption of the blood-brain barrier. The clinical manifestations of brain tumor edema also depend on the location of the tumor. Raghib et al. reported that cerebral edema was the most common complication at the skull base with a rate of 50% (28).

Uncontrolled cerebral edema can cause increased intracranial pressure and permanent neurological deficits and fatal acute herniations. Treatment strategies for high intracranial pressure consist of general measures, medical interventions, and surgical interventions such as decompression. These patients should be carefully monitored in the intensive care unit (36) Cerebral edema usually occurs during craniotomy for brain tumors. This may increase the risk of cerebral ischemia and worsen the outcome. The surgical team should identify the risk factors that may cause perioperative brain swelling and act accordingly (37)

Brain edema is caused by the brain, cerebrospinal fluid and blood volume exceeding the intracranial volume when the skull and dura are opened by the neurosurgeon. Removal of cerebral edema reduces the severity of retraction injury and the risk of cerebral ischemia during surgery (38).

Age, clinical status and intraoperative position, tumor volume, location, midline shift, peritumoral edema, preoperative dexamethasone use, intraoperative mannitol dose, blood pressure value, mean arterial hemoglobin, osmolality and PaCO2 values, and histopathology of the tumor can be counted among the risk factors (37). Chow et al. reported that preoperative seizure predicts the occurrence of postoperative seizures in meningiomas, and that postoperative seizure increases the risk of cerebral edema and hemorrhage in the first postoperative week (39).

Seo et al. reported that four doses of 0.5 g/kg of 20% mannitol were 51.6% effective in the treatment of edema caused by supratentorial brain tumors, and this dose reduced brain edema (40). Dexamethasone is a standard treatment for cerebral edema after brain tumor surgery. However, its side effects may adversely affect the quality and safety of care given to patients (41).

In the treatment of brain edema developing after intracerebral tumor surgery, if medical treatment is not sufficient and a regression occurs in the patient's glaskov scale, decompressive craniectomy (DC) can be applied. DC allows the edema to heal by reducing the pressure on the parenchymal tissue until it resolves. Despite great advances in our knowledge of intracranial pressure and DC, little is known about their role in patients with oncological pathologies.

In a study by Jacobo et al., including a series of 33 patients who underwent glial tumor operation, the average survival time after DC for the development of postoperative brain edema has been reported to be approximately 2 years. The results were found to be better compared to cases requiring DC secondary to cerebral hemorrhage, and it was noted that DC is life-saving in these patients and allows most patients to continue oncological treatment after recovery (34).

2.5. Venous infarction

Venous injury is the most well-known emergency cause of venous edema or infarction. Injury of cortical veins or dural sinuses can cause local or distant venous congestion, leading to postoperative cerebral edema (42). Damage to the surgical plane between the tumor and the cerebral cortex can lead to postoperative venous infarction (43).

In a study by Zhang et al. including a series of 212 patients with geriatric brain tumor, it has been reported that perioperative stroke occurred in 1.9% of patients with 30-day systemic complicationsa rate of 24.5%, and perioperative stroke was associated with previous stroke and previous liver disease (44).

2.6. Early postoperative seizures

Early postoperative seizures (EPS) are a common complication of brain tumor surgery. In studies in the literature, it was stated that postoperative Karnofsky performance index was found to be worse in patients with EPS who were operated for intracranial tumors. Having a history of seizures before surgery is a risk factor for EPS. It is evaluated that approximately one third of patients with EPS experience recurrent seizures within one year and this may indicate epilepsy. It has been reported that EPS is generally associated with permanent neurological deterioration (45).

Most studies usually report EPS rates for patients who have not had seizures before. Therefore, although the rate of EPS is frequently reported as

5-10%, it is estimated to be higher (46.47) EPS may recur within 30 days after surgery. Zhang reports perioperative seizures with a rate of 6.1% in geriatric patients who were operated for a brain tumor (44). The one-year recurrence rate is reported to be between 36.1% and 63% in the literature (46.48).

A general seizure rate of 5.1% and 6.1% has been reported in patients with supratentorial tumors. Seizures are generally rare in patients with infratentorial tumors (49). However, some patients with posterior fossa tumors may require temporary supratentorial surgery such as ventricular drainage. EPS can sometimes occur after infratentorial or supratentorial surgeries due to some perioperative complications such as meningitis. Oushy, in his study, revealed that awake craniotomy poses a risk for perioperative seizures (50).

EPS, which is associated with major complications such as hemorrhages, meningitis, and electrolyte disturbances that require surgical revision in many cases, can also cause neurological deterioration together with factors caused by brain tumor. Seizures may cause pulmonary complications due to aspirations in confused patients. Given the high adverse outcomes and relapse rates after EPS, many surgeons prefer to use prophylactic anticonvulsive drugs. On the other hand, a considerable number of researchers believe that the routine use of prophylactic anticonvulsants does not reduce the risk of postoperative seizures in patients who have not had preoperative seizures (51,52). In patients with high risk of EPS, prophylactic anticonvulsant use may be appropriate.

2.7. Infection

Surgical site infection (SSI) is a serious threat for neurosurgery patients, resulting in increased morbidity and mortality rates (53).

Kraniyotomi sonrası CAE'ler, ameliyat sonrası kozmetik sonucu etkileme riski olan cerrahi yara debridmanı, kemik fleplerinin çıkarılması, ve kranyoplasti gibi birden fazla cerrahi müdahale gerektirebilir (54,55). Ayrıca, intrakraniyal tümörlere sahip hastalarda enfeksiyon iyileşinceye kadar radyasyona ve kemoterapiye ara verilmesi gerekir. CAE kritik adjuvan onkolojik tedaviyi erteleyebilir (54).

The most common infectious agents in neurosurgery CAE are Staphylococcus and Streptococcal species, including S.aureus (56). The ideal prophylactic antimicrobial agent targets the most common organisms and has the narrowest possible spectrum of activity (57). Currently, most guidelines recommend a cephalosporin as antibiotic prophylaxis in neurosurgical procedures, and Cefazolin (a third-generation cephalosporin) is the most commonly recommended cephalosporin (58).

In a retrospective study involving 83367 patients who underwent resection of benign or malignant brain tumors, 22.8% of the patients were hospitalized for the second time due to complications due to the operation. The most common specific reasons for rehospitalization were post-operative infection (5.96%) and septicemia (4.26%) (28).

In a study by Zhang et al., including a total of 212 geriatric brain tumor patients, they reported 13.7% systemic infection and 1.4% central nervous system infection in 29 patients (44). Garza et al. found postoperative meningitis at a rate of 1.1% in 1000 cases (3).

2.8. System complications due to intraventricular chemotherapy

Advances in cancer treatment have caused leptomeningeal diseases to be seen more frequently. In leptomeningeal involvement, Ommaya reservoirs and shunt systems are preferred for intrathecal chemotherapy for treatment. Preferred systems for hydrocephalus are aimed at lowering intracranial pressure. Misplaced catheters, malfunction of the system, and infections due to shunt are among the complications that can be seen in such treatments (59).

Since chemotherapeutic agents are neurotoxic, it is very important to ensure that the chemotherapeutic agent reaches the ventricle, not the brain parenchyma, in patients with a reservoir placed in the oma. A case of encephalitis has been reported due to a misplaced Ommaya reservoir (60). A check with CT should be performed after operations in which such systems are fitted. Neuronavigation can be used intraoperatively to prevent complications in patients with small ventricles (61).

2.9. Hydrocephalus and complications of systems and methods used for hydrocephalus:

Communican or obstructive hydrocephalus can be seen in patients who have been operated for a brain tumor. Treatment may require insertion of a ventriculoperitoneal shunt (VPS) to the patient. High cerebrospinal fluid protein levels due to an intracerebral brain tumor may cause the ventriculoperitoneal shunt to become occluded and therefore inoperable. In appropriate cases, a third ventriculostomy may be attempted via endoscopy. Although third ventriculostomy can minimize the risks of shunt infections and shunt dysfunctions, the risk of hemorrhage should be kept in mind. In some patients with malignant brain tumors with leptomeningeal spread, peritoneal spread of disease after VPS placement should also be considered. The prognosis of leptomeningeal disease is poor. Therefore, patients may not survive long enough, and they may also encounter problems arising from peritoneal involvement (62).

2.10. Venous thromboembolic events

Venous thromboembolic events (VTE) can significantly complicate the postoperative period for neurosurgery patients. It is known that patients with brain tumors are particularly susceptible to VTE. In a study, the overall incidence of VTE was found to be 14.9% in patients with brain tumors. Deep vein thrombosis (DVT) was observed in 93.4% of these patients, pulmonary embolism (PE) was observed in 5.5%, and DVT combined with PE alone was observed in 1.1%. It has been reported that PE causes death in 0.3% of cases (63). DVT is the most common adverse event reported with a rate of 3%-26% (10). The incidence was found to be 21.7% in patients with sellar tumors, 13.8% in intracerebral tumors, and 7.9% in metastases, and it was concluded that the incidence of VTE depends on the type of tumor (63).

Thromboprophylactic anticoagulation is commonly used to prevent VTE, which carries the risk of intracranial haemorrhage. Among patients who underwent craniotomy for primary malignant brain tumor, complication rates for DVT, PE, and intracerebral hematoma were found to be 2.6%, 1.5%, and 1.3%, respectively. VTE is the second most common major complication and has been identified as the third most common reason for readmission. It has been observed that long operative time, advanced age and obesity increase the risk of VTE (64).

In addition to known surgical risk factors such as venous stasis from perioperative immobility, endothelial damage, and inflammation from the operation itself, cancer is a recognized risk factor for the development of VTE. Among all cancer types, high-grade gliomas have been reported to be one of the highest risks of perioperative VTE, and rates of postoperative VTE are twice as high when craniotomy for any brain tumor is compared with craniotomy for non-neoplastic disease (65). VTE has been reported as one of the most common major complications after craniotomy for brain tumors, with an incidence of up to 21% in the first 3 months after surgery (66).

Prophylaxis with mechanical, anti-embolism stockings or intermittent pneumatic compression devices is recommended until the end of postoperative hospitalization or until the patient is mobile. Combination prophylaxis with low molecular weight heparin or unfractionated heparin is recommended in patients without recent intracerebral hemorrhage or other active major hemorrhage (67).

2.11. Delirium

Despite its clinical importance, delirium remains an important problem due to its epidemiology, prevention or management, and inadequate recognition. Delirium is manifested by impaired consciousness, cognition, rapid onset and fluctuating course. The syndrome may be linked to an independently diagnosable brain or systemic disease or disorder. Diagnostic criteria for delirium are formulated in the tenth edition of the International Classification of Diseases (ICD-10) (68).

Gliomas represent approximately 80% of primary malignant brain tumors (69). According to the statistical study performed in patients who underwent brain tumor resection, it was reported that 18.6% of patients were diagnosed with postoperative delirium. Postoperative delirium describes a multifactorial disease process that occurs after surgery. Patients with delirium had a higher 30-day mortality rate compared to those without delirium (1.48% vs. 9.78%), and the number of days of hospital stay was higher (14.3 vs 6.3 days), seizures were more common (17.2% vs. 4.19%), and the mean operative time was longer (242 vs 220 min) (70).

In brain tumor patients, delirium has been associated with increasing age and preoperative use of benzodiazepines (66). Chen et al. reported the overall incidence of postoperative delirium as 14.78%, the incidence of hyperactive delirium as 50.76%, the incidence of hypoactive delirium as 41.67%, and the incidence of mixed delirium as 7.57% (71).

3. Conclusion

Patients with surgical complications of malignant brain tumors have higher complication rates, longer hospital stays, increased hospital costs, and significant increases in the risk of in-hospital mortality. An increase in iatrogenic stroke complications has been reported in studies conducted over the years due to studies reporting that maximal removal of malignant tumors increases survival. The mortality risk of patients with iatrogenic stroke increases nine times during their hospital stay (3). Therefore, it is necessary to adjust the profit-loss balance well.

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