Complications in Occipitocervical Surgery

Ali Fahir Ozer

Abstract

The occipitocervical junction is formed by the foramen magnum (FM) and the adjacent anatomical structures of the C1 and C2 vertebrae. The FM is formed anteriorly by the basilar part of occipital bone. Anterolaterally, it borders the occipital condyles and hypoglossal canal as well as the jugular foramen. Posteriorly, the FM is formed by the squamous part of the occipital bone with the internal occipital crest. In the midline, named landmarks at the anterior margin are the basion and, at the posterior margin, the opisthion. Vital anatomic structures are located in the FM or pass through. Among these are the medulla oblongata, meninges, anterior and posterior spinal arteries, vertebral arteries, and spinal roots of the accessory nerve. The FM is firmly anchored to the cervical canal via strong ligamentous support.

Pathologies in this area can be of congenital, acquired, traumatic, neoplastic, or infectious origin, with the respective surgical indications and approaches depending on the nature and location of the pathology. If the pathology is occipitoatlantal, the occiput is usually involved in surgery. On the other hand, if the pathology is only at the level of C1-C2, surgery may be limited to these two vertebrae.

In this section, we present the surgical management of exemplary congenital cases, and we discuss the complications and what needs to be done to deal with them.

Keywords

Occipitocervical anatomy · Occipitocervical measurements · Occipitocervical complications · Occipitocervical surgery

A. F. Ozer (✉)
Department of Neurosurgery, Koc University School of Medicine, Istanbul, Turkey

Part 1: Congenital Pathologies

Introduction

The occipitocervical region is a complex region with characteristic anatomical structures. Conceptually, as a spherical mass, the rigid head is attached to a long mobile cylindrical structure, the cervical region. This layout shows that the specific architectural features and musculoskeletal anatomy is very solid. To this end, the cervical region is firmly attached to the cranium via strong ligamentous support. The connective tissue in this area is much stronger than that connecting vertebrae in other parts of the spine. For this reason, occipitocervical stabilization carries significance when this structural relationship is weakened or compromised.

What is the common problem in occipitocervical region pathologies? The answer to this question is important: If the occipitocervical connection is disrupted, instability develops, neural tissue damage can occur, a severe neurological deficit may develop, and the patient might ultimately die. The aim of surgery is thus to restore normal structural integrity in a way that protects the critical structures of the cervicomedullary junction (CMJ). Because this region contains vital anatomical contents, even minor procedural mistakes or carelessness in management can result in high morbidity and mortality. Attention has to be paid from the very beginning to the patient's position. The surgeon who performs the operation often has to position the patient in rigid skeletal fixation and carefully adjust alignment. Radiographic control is mandatory. For example, in cases of occipitoatlantal or atlantoaxial shifts resulting in an anterior deformity, the spinal canal opens when the patient has been brought into extension. Conversely, if the head is fixed in flexion, the spinal canal will be narrowed and the CMJ compressed. If the head position remains misaligned during surgical decompression, fusion and instrumentation may be difficult and insufficient.

The safest and easiest way to reach the pathology should be chosen, and all available technology should be used.

© The Author(s) 2025

K. Turel, E. M. Kasper (eds.), *Complications in Neurosurgery II*, Acta Neurochirurgica Supplement 133,
https://doi.org/10.1007/978-3-031-61601-3_18

Surgery should be performed with neuromonitoring, navigation, and real-time radiographic control (e.g., O-arm) as indicated [1–8].

Sufficient experience, correct planning, and choosing the most appropriate approach are necessary for surgical success. Most of the complications are due to a lack of expertise, incomplete surgical approaches, or overtreatment. While unnecessary surgery increases the risk of complications, incomplete surgery eliminates the chance of success.

Congenital Anomalies

Congenital pathologies of the occipital bone can be due to developmental anomalies (e.g., hypoplasia or agenesis) or segmentation disorders. Developmental anomalies include hypoplastic disorders of the occipital area, basioccipital hypoplasia, and occipital condyle hypoplasia. Basioccipital hypoplasia is the formation defect of four occipital sclerotomes. It results in a hypoplastic or short clivus and/or basilar invagination. This anomaly is best measured with the Chamberlain line. Occipital condyle hypoplasia results in a short and flat condyle, leading to limited movement and basilar invagination. Although the deformity is mostly bilateral, it can be seen unilaterally.

Segmentation Anomalies

Atlas Assimilation Segmentation disorders are the most caudal elements of the skull base and C1 can lead to atlantooccipital assimilation. In this scenario, the atlas adheres to the skull base at the level of the foramen magnum. Adhesion may be complete or partial and often occurs with basilar invagination. Restrictions to the range of motion between C0 andC1 can lead to instability at C1-C2. Of those patients with such atlantooccipital assimilation, 50% develop C1-C2 instability and myelopathy, which usually occurs around the third decade of life.

Congenital Anomalies of the Atlas Except for atlantooccipital assimilation, atlas anomalies do not compromise the anatomical relations of the occipitocervical region and do not result in basilar invagination.

Congenital Anomalies of the Axis Most congenital anomalies of the axis are dens related and lead to basilar invagination. However, they can also cause atlantoaxial instability. Atlas anomalies are occasionally mistaken as fractures. Axis ossification centers allow us to understand the pathogenesis of these anomalies: The axis has three ossification centers, of which two are columnar centers that ossify, prenatally forming the dens body, and the last one is located in the tip of the dens (apex).

Os Odontoideum (Persistent Ossiculum Terminale or Bergman Ossicle) This characteristic radiographical feature occurs as a result of the nonunion of the terminal ossification center of the odontoid and the remaining part of the dens. It may be confused with a high-riding type I odontoid fracture. However, it has little clinical significance. The dentocentral synchondrosis normally fuses at about the age of 6 years. Os odontoideum hence develops as a result of the fusion failure of the dental synchondrosis line. Although os odontoideum is often radiologically confused with an odontoid fracture, the thick and round upper cortex of C2 and the round anterior arch of C1 allow us to distinguish these two entities. Os odontoideum may cause atlantoaxial instability. This condition is frequently seen in individuals with Down syndrome, spondylo-epiphyseal dysplasia, Morquio syndrome, and some other congenital connective tissue diseases. The total aplasia of the odontoid is very rare. Os odontoideum, which is seen clearly above the arch of the atlas on an anterior to posterior (AP) open-mouth radiograph, is rarely confused with odontoid aplasia [9–13] (Fig. 1).

Atlantoaxial Facet Joint Anomalies This category is divided into type I and type II.

Type I: Here, the atlas facets slide on the axis, and spondylolisthesis develops because of sagittal malalignment. In this type of basilar invagination, the odontoid migrates upward and backward and compresses the brainstem. Neurological deficits may develop. It is mostly seen in young patients with acute and severe clinical symptoms. By pulling the odontoid with traction or by using distraction with an inter-facet spacer, normal alignment can be re-established, and stabilization is accomplished via C1-C2 fixation (Fig. 2).

Type II: Type II is defined by central facet dislocation. Over time, changes in bone and soft tissue result in instability. The odontoid is pushed toward the clivus together with the atlas at the level of the foramen magnum. Over time, the atlas assimilates into the occiput and the bones fuse. Consequently, the atlas disappears, almost becoming an extension of the occiput. In Type II invagination, the atlantodental interval (ADI) remains normal. Chiari malformation and syringomyelia may develop secondarily. Traction and intra-facet maneuvers may be insufficient to restore alignment in Type II abnormalities. Anterior decompression and posterior occipitocervical fusion and instrumentation may be required [14–19] (Fig. 3).

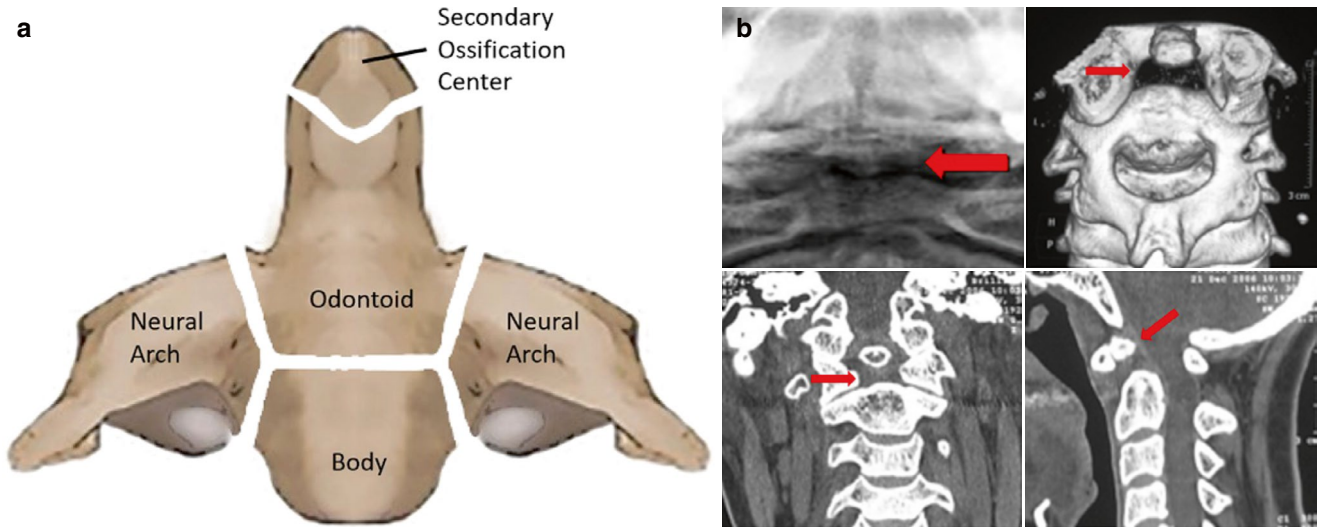


Fig. 1 (**a**) Ossification centers in the odontoid, (**b**) os odontoideum. The latter is a congenital anomaly, often confused with odontoid fractures as the most important cause of atlantoaxial instability

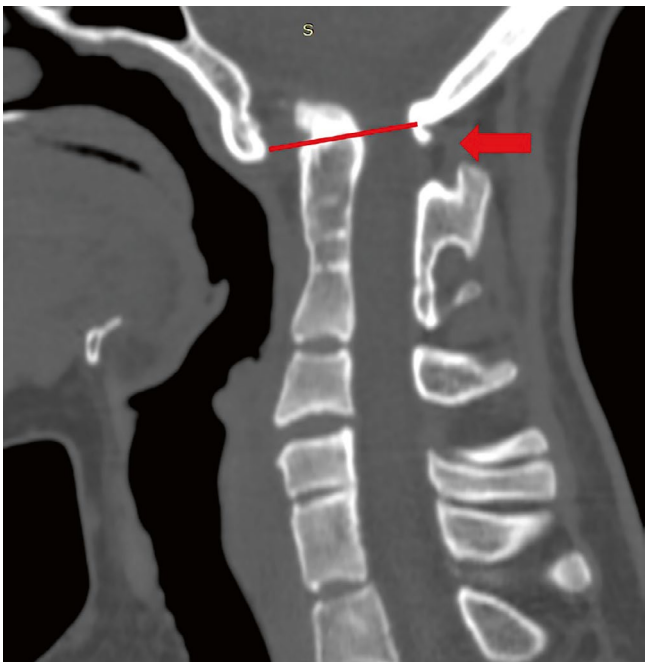


Fig. 2 Goel type I basilar invagination with atlas assimilation



Fig. 3 Goel type II basilar invagination. The odontoid pushes on the clivus, and both compromise the neurocranium at the level of the foramen magnum

If we look at the treatment complications that occur in patients with congenital anomalies, the most common one is related to atlas assimilation.

Case Study A 57-year-old female patient presented with complaints of an inability to use both her hands, numbness, gait instability, and difficulty walking (Fig. 4). The patient underwent decompressive surgery for spinal cord compro-

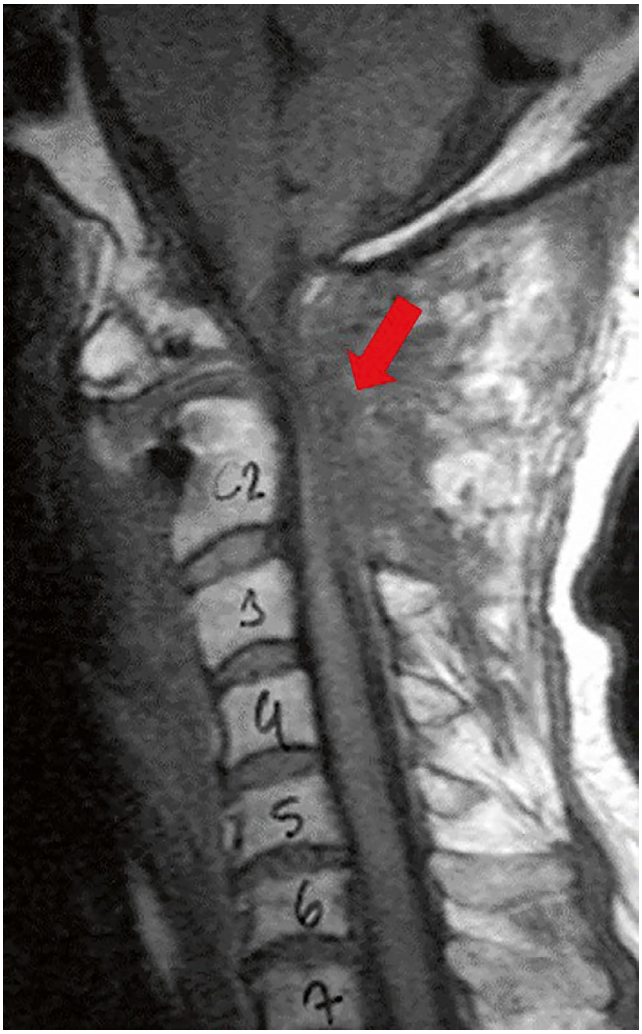


Fig. 4 Spinal cord compression caused by anterior shift (translational instability) due to os odontoideum. This scenario was further destabilized by a C1-C2 laminectomy, which led to the formation of fibrous tissue and the development of the postlaminectomy membrane

mise at C1, but the patient became worse after the operation and then could not walk at all. She was bedridden and largely unable to move her hands or arms. According to the post-OP magnetic resonance imaging (MRI), the patient had an os odontoideum. What had happened? The unnoticed os caused spinal cord compression since the C1 vertebra and the os odontoideum shifted forward during surgery, and the posterior arch of the atlas compressed the spinal cord. The removal of the C1 and C2 laminae caused increased instability. The already-unstable C1-C2 joint showed an increase in mobility with the destruction of the posterior tension band, and a reactive membrane formed at the laminectomy site. There was excess connective tissue production to keep the alignment tight, resulting in compression. Unfortunately, this patient did not accept any revision surgery.

The right intervention here would have been to stabilize the C1-C2 junction with the Goel-Harms or Magerl methods or at least by placing graft material between C1-C2. Since this stabilization includes retracting C1, already effectively widening the canal, further laminectomy may not have been necessary.

Another complication occurring in the setting of an os odontoideum is related to the stabilization technique. A 40-year-old male patient presented to a hospital with complaints of weakness and numbness in his arms and legs for about 3 months. On examinations, he was diagnosed with atlantoaxial dislocation due to the fracture of the dens, and stabilization surgery was recommended. The patient underwent surgery, where the C1-C2 spinous processes were tied with wires. The C1-C2 posterior laminae were fused by placing an interposition bone graft between them. At the time of a follow-up examination 1 year later, the wires were loose, and revision surgery was recommended. While stabilizing C1 and C2 according to Magerl's technique, fusion was performed by placing a new bone graft between the laminae. At postoperative controls, C1-C2 had fused well, and there were no problems at the 10-year follow-up (Fig. 5).

No real mistake was made during the primary surgery in this case, but stabilization with wires only is known to be biomechanically weak. Goel-Harms or Magerl techniques of rigid occipitocervical fixation should be preferred in such cases [3, 20, 21].

Another case represents the overtreatment of an os odontoideum. This patient was a 32-year-old man with complaints of numbness, clumsiness in both hands, and balance problems, which had been increasing over 6 months. On clinical assessment, mild quadriparesis was found. Radiographic examination showed atlantoaxial dislocation, possibly due to dens fracture, and myelomalacia was detected in the spinal cord. Surgery was performed elsewhere. Occipitocervical stabilization was performed. The patient's neurological status improved considerably, but he stated that his quality of life deteriorated because he could no longer move his head properly (Fig. 6).

In this case, the occiput was unnecessarily included in the fusion surgery, resulting in a loss of all head movement. The original pathology was at the C2 level, and as a result, only the C1-C2 relationship had been impaired. Fixating the C1-C2 by using the Goel-Harms or Magerl transarticular technique would have been an adequate surgical method. In addition, extended surgery carried a higher risk, including potential pseudoarthrosis and the risk of infection since surgery was prolonged. Most importantly, though, an unnecessary loss of range of motion was inflicted on the patient.

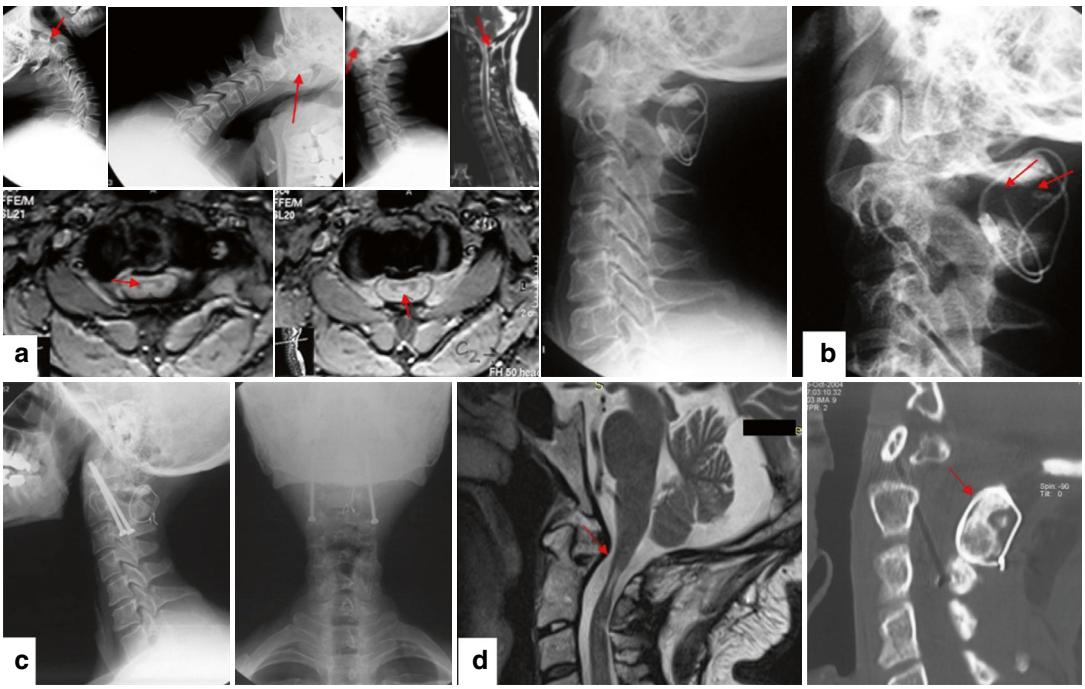


Fig. 5 (**a**) Patient with atlantoaxial dislocation due to the os odontoideum. Signal changes indicate myelomalacia of the spinal cord due to chronic compression. This patient underwent stabilization with C1-C2 wires. (**b**) The wire construct at C1-C2 failed over time as seen in the control radiographs performed after 14 months. Comparison of XR obtained immediately after the first surgery to X-rays displaying the findings after 14 months, (**c**) status after C1-C2 stabilization (Magerl) and bone graft placement, (**d**) posterior fusion is observed at 4 years. The old myelomalacia of the spinal cord remains visible with the canal effectively enlarged

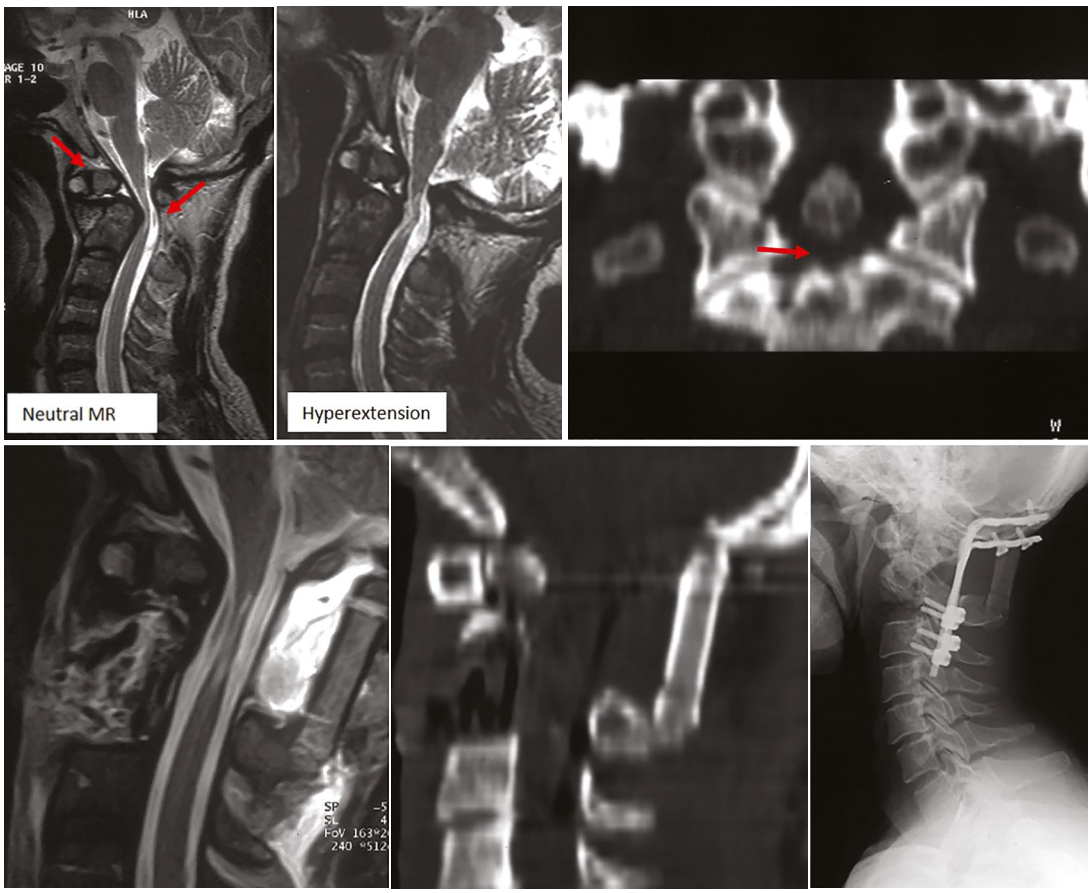


Fig. 6 In this patient, C1 was anteriorly dislocated over C2 due to Os Odontoideum fracture. The resulting problem is C1-C2 instability which requires fixation. In this case, the occiput was used to place bone graft and occiput-C3 fixation was performed. The odontoid was removed transorally and effective expansion of the spinal canal was achieved

Another Case Study A 35-year-old female patient presented with imbalance, dizziness, and dysphagia for 6 months. Chiari malformation with impaired CSF circulation and mild hydrocephalus were detected during the MRI examination (Fig. 7). C1 laminectomy and suboccipital craniectomy were performed with duraplasty to re-establish normal CSF flow. However, the patient became worse after surgery, to the point of impaired consciousness. Emergency computed tomography (CT) and MRI revealed obstructive hydrocephalus, including an enlarged fourth ventricle, due to the further descensus of the tonsils blocking CSF passage. An urgent ventriculoperitoneal shunt was placed. The patient recovered slowly, and she was discharged 3 weeks later.

An important error in management occurred here: The mistake was to not evaluate the patient well preoperatively. First, hydrocephalus could have been treated with a ventriculoperitoneal shunt from the beginning. Then, while decompressing the craniocervical junction (CCJ), too much bone was removed, which resulted in the sagging of the posterior fossa contents, leading to complete obstruction. Performing too wide a craniectomy is a technical mistake.

This complication teaches us another important lesson: Surgeons have to make sure that the CSF passage is open. In our institution, after opening arachnoid adhesions around the cerebellar tonsils, we routinely place silicone tubes bilaterally to ensure CSF flow from the cerebellar cisterns to the cervical subarachnoid space. This technique can also be used for other clinical pathologies, such as traumatic syringomyelia [22].

Finally, we have another case study of a CCJ complication occurring in a patient with a congenital anomaly: The patient, a 33-year-old man, presented to us with complaints

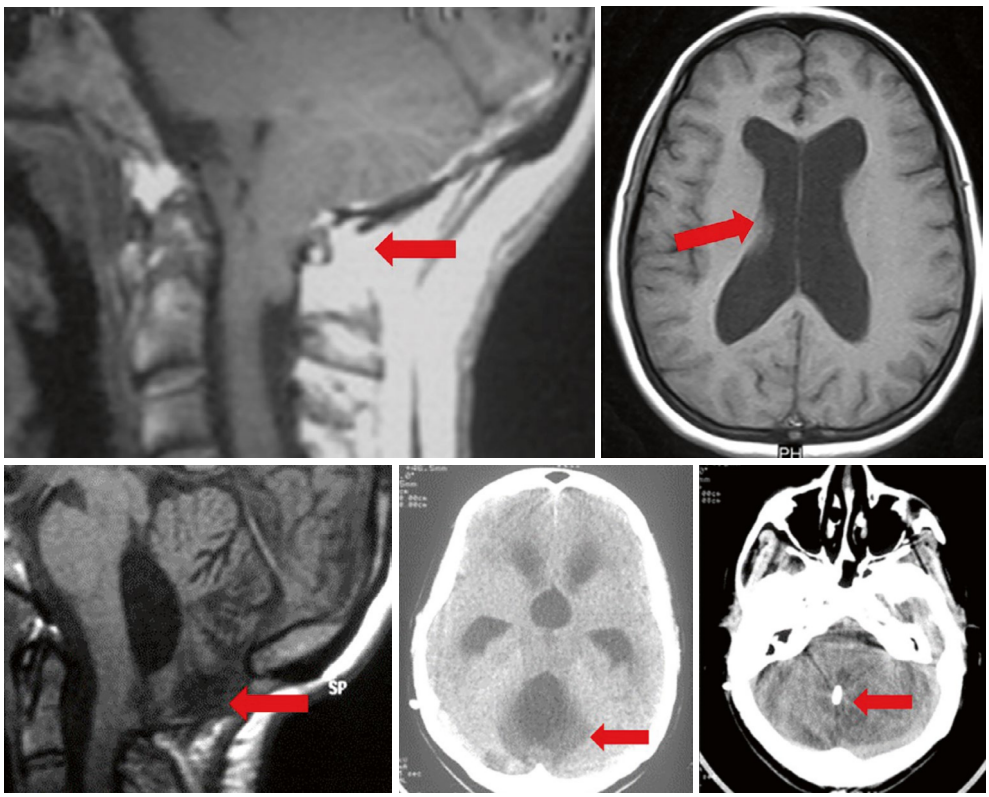


Fig. 7 A 30-year-old female had problems with imbalance, dizziness, and dysphagia for the last 6 months. Chiari malformation and mild hydrocephalus were detected in the MRI examination. Due to extensive suboccipital craniectomy, the cerebellar tonsils drooped and completely blocked the passage of CSF in the foramen magnum. The patient developed acute hydrocephalus and the enlargement of the ventricle was remarkable due to the discharge of CSF trapped in the fourth ventricle. The patient entered the herniation process. She was treated with emergency VP and fourth ventricle shunts

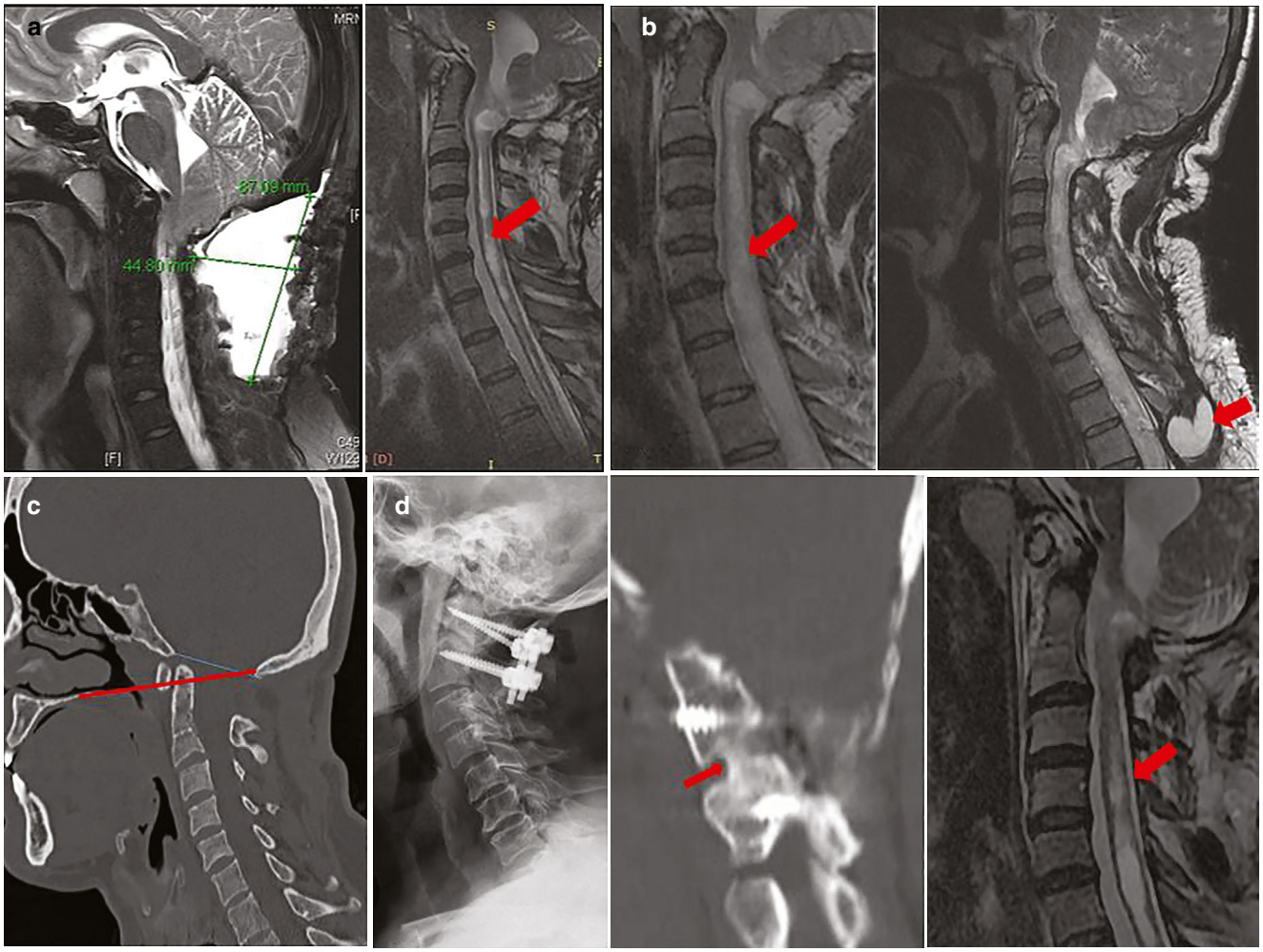


Fig. 8 The patient, who was diagnosed with syringomyelia and Chiari malformation in 2012, underwent posterior decompression surgery in 2013. Suboccipital craniectomy and duraplasty were performed. Pseudomeningocele developed in the early period, but it resolved spontaneously. The patient's syringomyelia improved after the operation. In the MRI examination performed in 2016, the syringomyelia, which had initially disappeared in the early period, recurred. (**a**) Shows the pseudomeningocele that had transiently formed postoperatively. (**b**) Shows the recurrent syringomyelia that had formed in a delayed fashion after initial improvement as seen in the panel to the left of the top row. (**c**) After reevaluation, it was determined that the patient had Goel type 1 basilar invagination. The condition was stabilized with screw and rod system. C1-C2 facet joint was distracted with small bone grafts in both sides. The canal was widened by performing duraplasty in craniovertebral junction. (**d**) In the last control of the patient in 2020, the syringomyelia had recovered, the subarachnoid space was opened, and the patient had recovered neurologically, and he was able to do his daily work independently

of weakness in his hands and feet, difficulty walking, and feeling unsteady when standing for the last 3 months (Fig. 8). The patient displayed clinically mild quadriparesis and radiographically extensive syringomyelia from the upper cervical to the thoracic spinal cord. In this case, suboccipital craniectomy, C1 laminectomy, and duraplasty were performed. Three years later, the syringomyelia had reformed, and a syringopleural shunt was performed, leading to the resolution of his symptoms. Repeat MRI after an interval revealed that the syrinx had recurred. However, when all imaging was reviewed carefully, type I basilar invagination was noted. A third operation was undertaken to pull the odontoid away from the foramen magnum. It was planned to revise the duraplasty and to put a bone graft between C1 and C2. Following this, C1 and C2 were stabilized with screws. This strategy succeeded, where the syrinx nearly resolved after the operation. No high-pressure fluid collection formed. The patient gradually returned to normal neurological status, and MR has remained stable since surgery.

An error in judgment was made here by initially overlooking the basilar invagination, which led us to treat the patient inadequately (assuming a simple Chiari malformation). The syringomyelia could have been corrected with suboccipital decompression alone in simple cases, but the added complexity of an odontoid in the foramen magnum from the basilar invagination made this a complex scenario preventing the passage of normal CSF flow.

Lastly, we mention the anatomical variant of a high-riding vertebral artery, which is an important pathology in this region. In fact, it can be encountered in healthy people and can be found

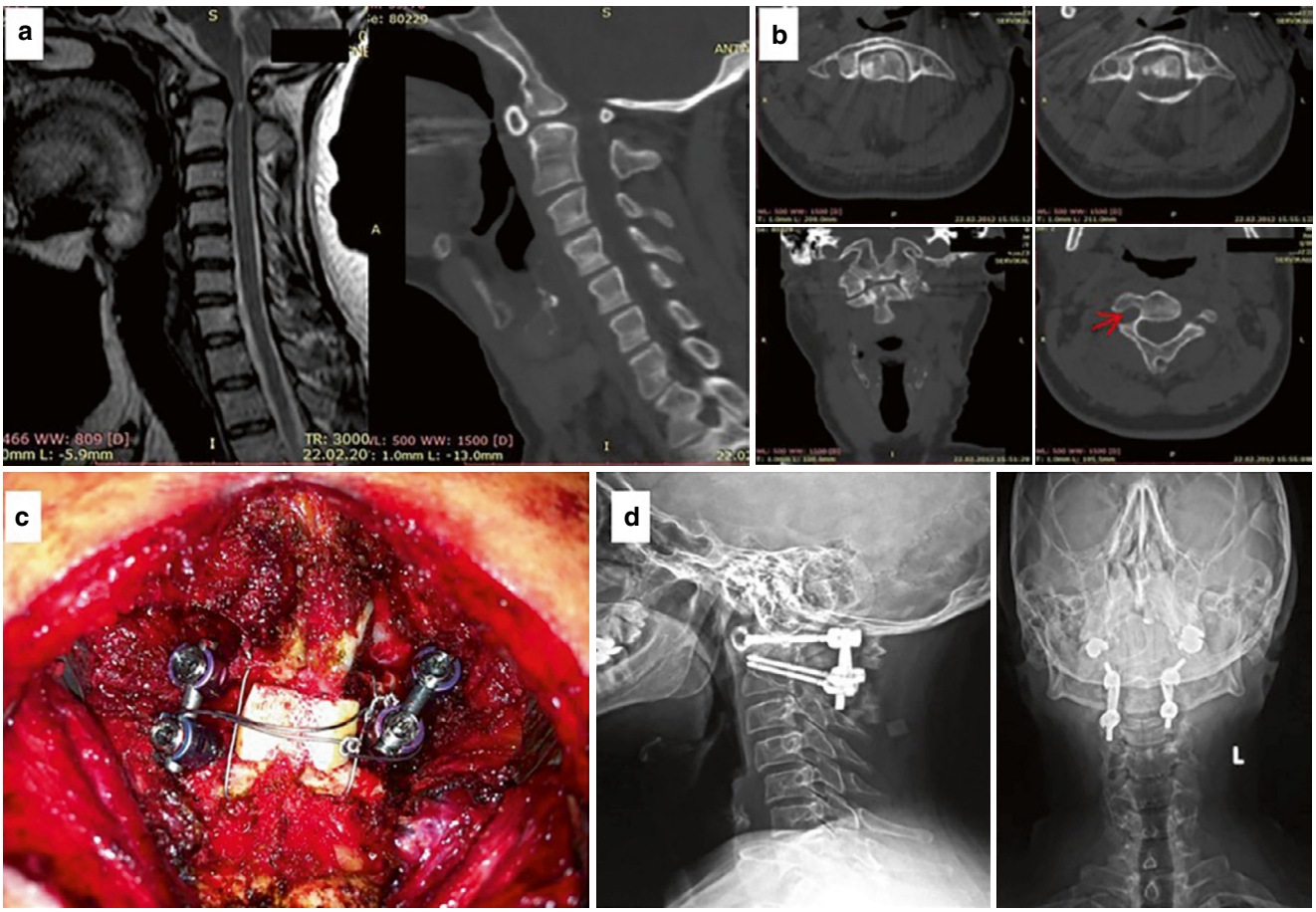


Fig. 9 (**a**) Atlantoaxial instability due to os odontoideum as seen on T2 MR images and CT with myelomalacia on MR and narrowing in the canal on CT. (**b**) On the right, it is seen that the highly located vertebral artery enters the C2 corpus (high riding vertebral artery). (**c**) The bone graft placed during the surgery. (**d**) C1-C2 stabilization was performed using the Goel-Harms technique with navigation

in the treatment of other pathologies, such as trauma and tumors. It should come to light in presurgical imaging examinations.

The patient, a 25-year-old male worker, felt tired and weak while working. The patient displayed neurologically mild quadriparesis, and he was also diagnosed with atlas assimilation and C1-C2 dislocation at the time of the preliminary examinations. The right vertebral artery was noted as having taken a variant medial course (high-riding vertebral artery) on CT angiogram (Fig. 9). Navigation and an O-arm were used during surgery. Screws were placed using the Goel-Harms technique. During screw placement at C2, the trajectory aimed at the isthmus of C2 by assessing the course of the vertebral artery and using navigation. Navigation and an O-arm are recommended in such cases to prevent injury to the high-riding vertebral artery.

Conclusion

Surgery in the occipitocervical region requires particular diligence to preserve vital nerve tissue. Carefully examining each patient is necessary to identify and apply the appropriate treatment. A surgical procedure should be pursued only after a complete examination and after a comprehensive assessment of radiological studies, to prevent complications. The treatment of these regional pathologies should be carried out with sufficient technology and expertise.

Part 2: Acquired Pathologies

In this article, we discuss the surgical management of craniocervical pathologies caused by acquired disorders, traumas, tumors, and infections and give case studies of complications. This group of patients constitutes the major group of craniocervical region pathologies that require special treatment.

Acquired Disorders

Paget's disease, osteomalacia, rickets, osteogenesis imperfecta, rheumatoid arthritis, and neurofibromatosis are frequently seen among the acquired diseases that soften and disrupt the bone and soft tissue structures at the skull base.

The upward migration of the odontoid as a result of the softening of the skull base results in basilar impression.

Diseases that disrupt the ligamentous structure of the occipitocervical region, such as rheumatoid arthritis, can also cause the upward migration of the dens, called cranial settling. Rheumatoid arthritis and psoriatic arthritis are chronic, systemic inflammatory diseases that disrupt the synovial layer, leading first to synovitis and subsequently to the destruction of the articular cartilage and postinflammatory ankylosis. In rheumatoid arthritis, inflammatory pannus formation is seen in the synovial joints. Supporting ligamentous structures are also damaged as a result of cytokine release. Psoriatic arthritis is observed in 1–2% of patients with psoriasis, and it disrupts the synovial joints via the same mechanism. In these diseases, both the occipitocervical region and the subaxial cervical spine are affected, and damage to the ligaments results in atlantoaxial instability. The atlantodental interval (ADI) is a very important measure for assessing this pathology. With the progression of the disease, erosions of the occipital condyles, C1 lateral masses, and C2 facets are observed. This erosion causes the head to further misalign, causing CCJ obstruction with myelopathy and even increased intracranial pressure and other neurological deficits. In patients with advanced rheumatoid arthritis (RA), the dens impales the neurocranial space even higher as vertical subluxation increases, leading to compression on the brain stem and vertebrobasilar system, which can lead to sudden death. Once patients present with an ADI > 10 mm, complete neurological recovery is unlikely even after surgery [22–25].

Case Study Rheumatoid Arthritis A patient presented to our hospital complaining of difficulty walking, gait instability, and numbness in his hands and feet for about 20 years. MRI showed no significant compression on the brain stem, but the dens was completely transformed into an inflammatory pannus, and atlantoaxial instability was demonstrated. Neurologically, the patient displayed mild quadriparesis. No remaining osseus odontoid was seen on CT. Occipitocervical fusion was indicated and performed with a horseshoe plate connecting the occipital bone to the cervical lateral mass. However, at radiographic follow-up 1 year later, the screws had loosened and pulled out. At revision surgery, a different horseshoe construct design was used, one that added wires to the vertebral laminae. No problems were detected in subsequent control studies. The technical mistake in the first operation was that the lateral mass screws that were used turned out to be too short. Importantly, the inflamed bone quality is often not good in patients with rheumatoid arthritis. A diligently employed

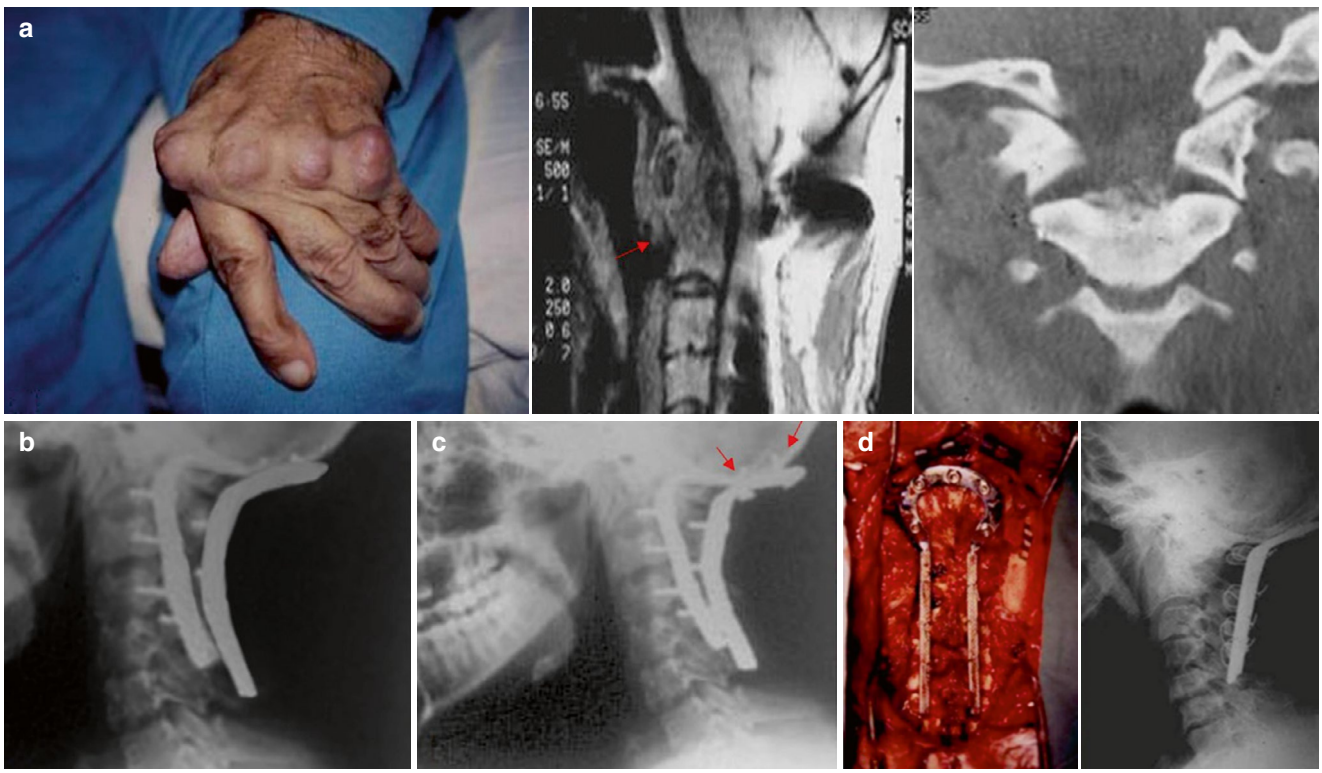


Fig. 10 A patient with rheumatoid arthritis who was treated 20 years ago: (**a**) C2 pannus formed, and spinal cord compression formed; he also had C1-C2 instability. (**b**) The patient underwent occipitocervical stabilization surgery. (**c**) The screws were removed after 1 year. (**d**) The patient was taken to surgical intervention again; occipitocervical stabilization was achieved by attaching the occipital bone with screws and more tightly connecting it to the cervical region with wires

sublaminar wiring technique may be more advantageous in such cases than screws alone (Fig. 10).

Trauma

Cervical spine injury has been observed in as many as 2.4% of blunt trauma patients, and 34% of these injuries occur in the occipitocervical region. Any ADI > 5 mm in an adult patient should be considered as pathological indicative of atlantoaxial instability. A highly sensitive measurement to determine atlantooccipital compromise is the "Harris rule of 12" method. In this assessment technique, the basion–dens measure (BDM) and the basion–axis measure (BAM) are carefully measured (see Appendix). According to Harris and colleagues, 95% have a BDM and 98% a BAM value that does not exceed 12 mm in adults. Any such interval >12 mm is considered abnormal and indicates instability deserving stabilization.

Occipital Condyle Fracture This is a rare injury type and was first described in victims who died after trauma. These fractures are classified according to the degree of damage to the ligaments or bone. Fractures with large bone fragments are more stable and have a better chance of healing with conservative treatment. CT with parasagittal and coronal reconstructions is useful in identifying occipital condyle fractures.

Atlas Traumas Jefferson was the first to describe a characteristic burst fracture of C1 after axial load injuries. Stability in this setting can be determined through open-mouth dens X-rays. According to Spence and colleagues, a simple rule applies in this setting: If the lateral displacement of both lateral masses of C1 are (combined) more than 7 mm apart above the matching joint surfaces of C2, the fracture is considered unstable because of transverse ligament damage, and surgical stabilization is required.

Axis Traumas After blunt trauma, C2 fractures occur in as many as 24% of cervical fractures, and among these, one-third show an odontoid fracture. The location, separation, and angulation of the fracture elements are important prognostic factors for healing and for treatment algorithms. The displacement of the fractured dens segment is measured from the anterior margin of the fractured part to the anterior break-off point at the C2 base. The D'Alanso classification into three dens fracture types remains popular today. Type I is an apical fracture, type II is a dens fracture at or above odontoid base, and type III is a C2 corpus fracture. In type IIA, additional corpus fragments are found at the base of the odontoid. Many displaced type II and IIA injuries require surgical intervention.

Traumatic Spondylolisthesis of the Axis The management of this classic injury type (Hangman's fracture, which was first described in executed death-row prisoners). It was well described by Levine and Edwards in 1985 (*Levine AM, Edwards CC. The management of traumatic spondylolisthesis of the axis. (1985) The Journal of bone and joint surgery. American volume. 67 (2): 217–26*). The alignment to the adjacent level bones is disrupted by pars interarticularis fractures. Some of these fractures are unstable and require surgery, whereas others can recover with conservative treatment [26–28].

Clinical Study of C2 Traumatic Spondylolisthesis A 32-year-old female patient sustained a traffic accident, after which she complained of severe and constant neck pain. Her neurological status was normal, but on radiographic examination, she was found to have an unstable type II C2 fracture, which was stabilized at C1-C2 with the Goel-Harms technique. One month later, another ligamentous disruption was identified at the C3-C4 level. The patient was taken back to surgery, and her lateral mass screws were extended to C5 (Fig. 11).

This case teaches us an important lesson: If a very prominent major pathology (C2 fracture) is present in the first trauma assessment, it may cause us to overlook other injuries. For this reason, all initial radiographic trauma studies should be carefully reviewed again without time pressure, and the possibility of multitrauma should be kept in mind.

Another case was seen in a young university student, who also had a traffic accident and experienced severe neck pain, for which she was taken to a local hospital. The patient was neurologically intact but was diagnosed with a minimally displaced type II odontoid fracture. Conservative treatment was recommended. A halo brace was fitted, and the patient was discharged with instructions for follow-up (Fig. 12). After an unremarkable initial period, the patient was admitted 8 months later to our department with neck pain and a noticeable limitation in her neck movements. Radiological examinations revealed that the dens fragment was anteriorly displaced, with the atlas and half of the odontoid fused with the vertebral body of C2. Over time, the fracture had healed in misalignment. However, a different problem was caused by the slip since the distance between the occiput and the

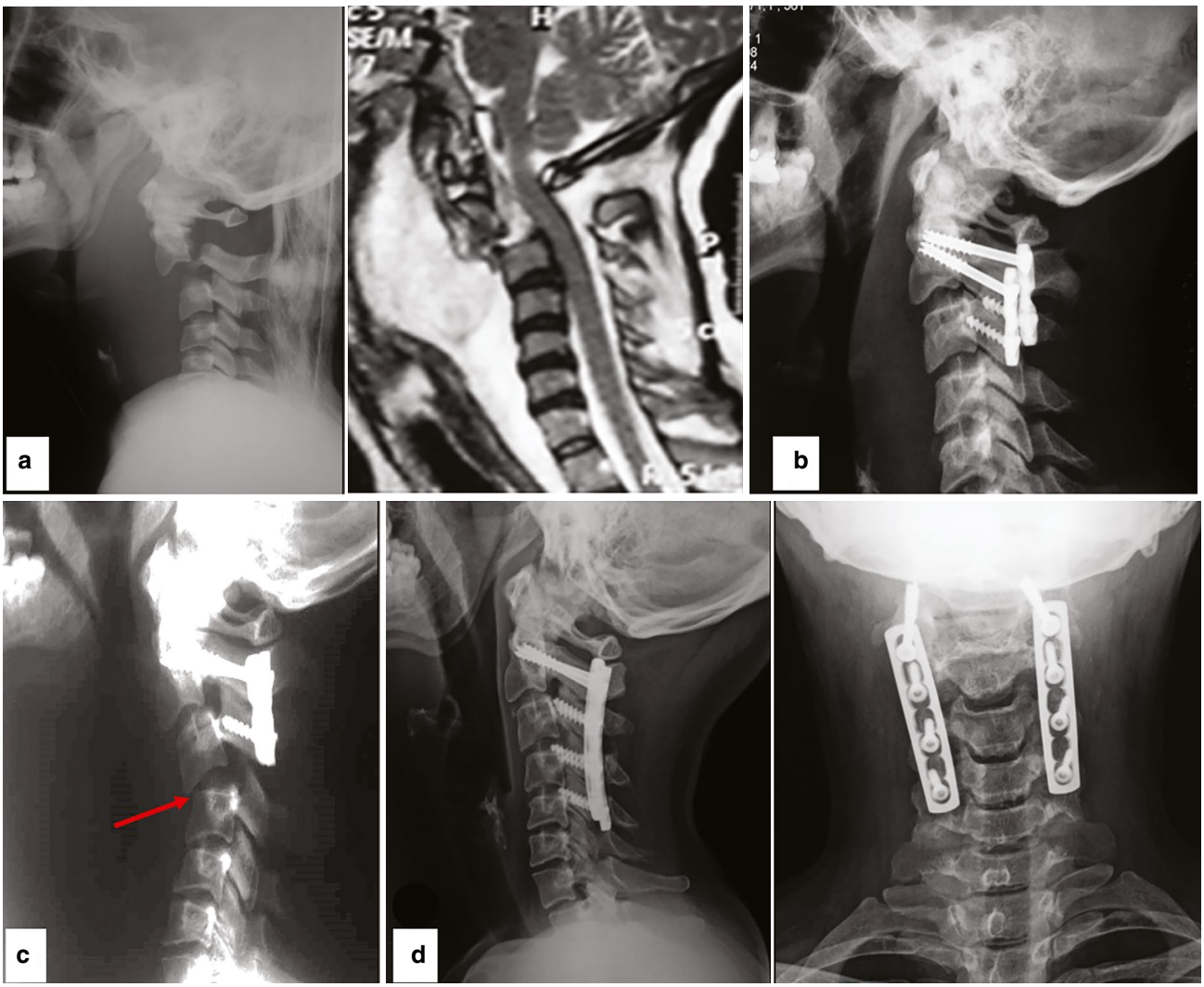


Fig. 11 The patient was a 32-year-old woman who had a traffic accident. She had severe and constant neck pain after the accident. It was evaluated as neurologically normal. (**a**) She had an unstable Levine–Edwards type IIII fracture on her radiological examinations, (**b**) we stabilized C1-C2 with the Goel-Harms technique, and the patient was discharged happily. (**c**) We found that there was a dislocation. (**d**) The patient was reoperated, and lateral mass plates lowered the plate in C2-C3 to C4 and C5

body of C2 had narrowed, causing spinal cord compression. We successfully addressed this by simply performing an occipital craniectomy, and no further intervention was needed for the misaligned odontoid, which had already fused. The lesson to be learned here is that some complications can be corrected by timely intervention. If the patient had represented in the first 6 weeks after the accident and before complete fusion, she still could have had a chance for an anterior approach [29]. A better initial solution could have been the placement of an anterior screw for the odontoid fracture, which should be performed under fluoroscopic alignment. This way, neck movement could have been preserved in this young patient.

Tumors

Occipitocervical region tumors either originate from bone structures or neural or soft tissues in the region or arise from a secondary spread to this region. These lesions are often divided into extradural, intradural-extraaxial, and intradural-intraaxial pathologies. The most common extradural tumors are metastases and chordomas. Other pathologies include primary bone tumors, such as chondromas, chondrosarcomas and osteoblastomas, plasmacytomas, eosinophilic granulomas, giant cell tumors, and aneurysmal bone cysts.

The most frequent intradural-extraaxial tumors in this region are schwannomas and meningiomas. Intradural parenchymal tumors are rare and include ependymomas, gliomas,

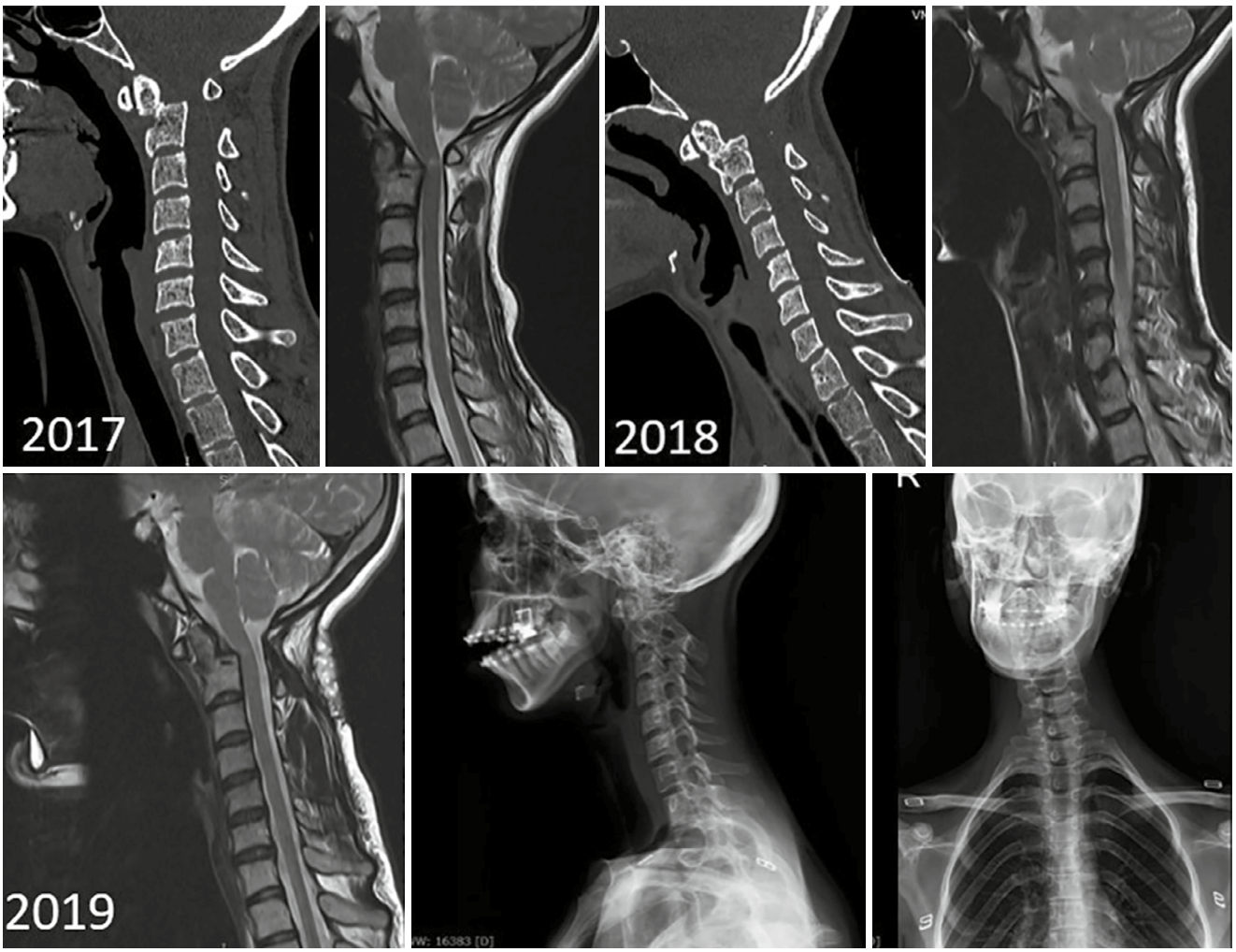


Fig. 12 This patient came after a traffic accident with a Type II fracture that was conservatively treated. At follow-up 1 year later, CT detected that the odontoid fused incorrectly and on MRI, there was narrowing of the foramen magnum. Suboccipital craniectomy was performed, but there was nothing to be done for the impaired odontoid and the cervical deformity

hemangioblastomas, dermoids, epidermoids, Wilms tumors, plexus papillomas, lipomas, metastases, and mixed tumors. Most of the latter originate from glial cells, ependymas, or astrocytes. Tumors originating from the fourth ventricle or the lower part of the cerebellar hemisphere or vermis may also secondarily extend into the occipitocervical region, but their origins exceed the scope of this manuscript [30].

A rare case with an important anatomic variant that was noticed only during surgery is now presented. This patient was a 48-year-old woman who complained of neck pain, early fatigue, and gait instability. On radiological examination, an intradural, extraaxial mass was detected at the level of the foramen magnum, resulting in left-sided compression on the spinal cord (Fig. 13). The working diagnosis was a possible neuroma at the C1-C2 level, and the left vertebral artery that entered through the foramen magnum was pushed over to reside exactly in the midline, which can be an anatomical variant or secondary to the mass effect of the tumor. Identifying this scenario is crucial because the aberrant vertebral artery (VA) in the midline can suffer iatrogenic damage during surgery. In tumor surgery in this region, vascular topography should thus be studied via CT angiography or ordinary angiography.

Infections

Surgical site infection is one of the most feared postoperative complications since it leads to higher morbidity and mortality and, subsequently, increased healthcare costs. It is associated with longer hospital stays and worse patient outcomes. Researched have reported that the incidence of infection in spine surgery is between 0.65% and 12%, depending on the type of surgery and the target population [4, 31, 32]. Numerous studies have attempted to identify the risk factors

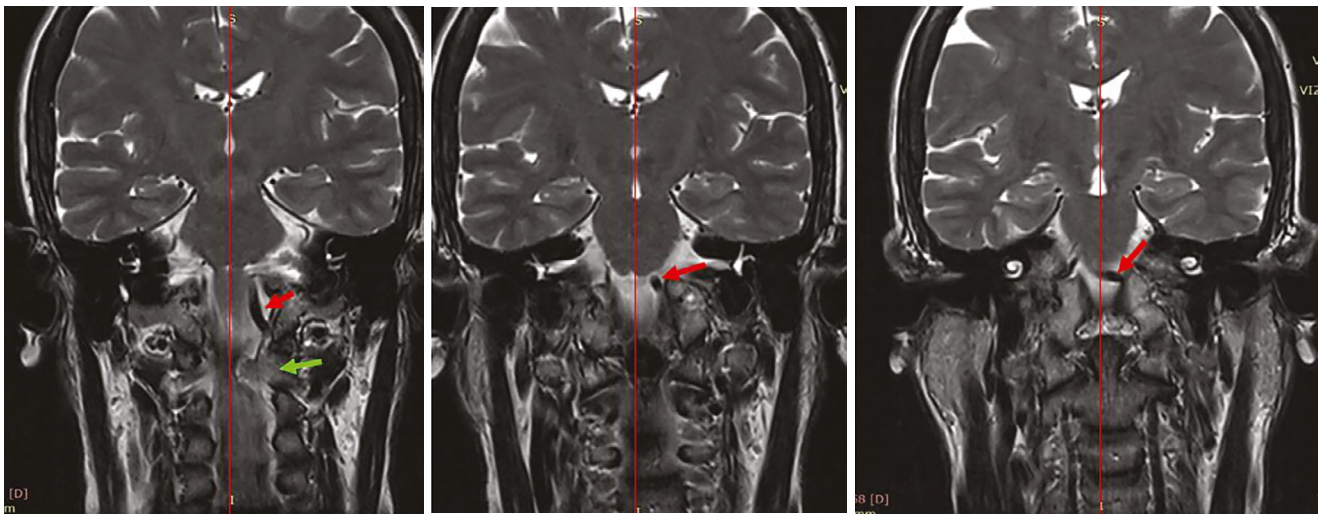


Fig. 13 Vertebral artery anomaly in the midline. Normally, the vertebral artery is not this medial, which puts it at considerable risk at surgery. Lower left neuroma progressing towards the foramen is seen (*green arrow*)

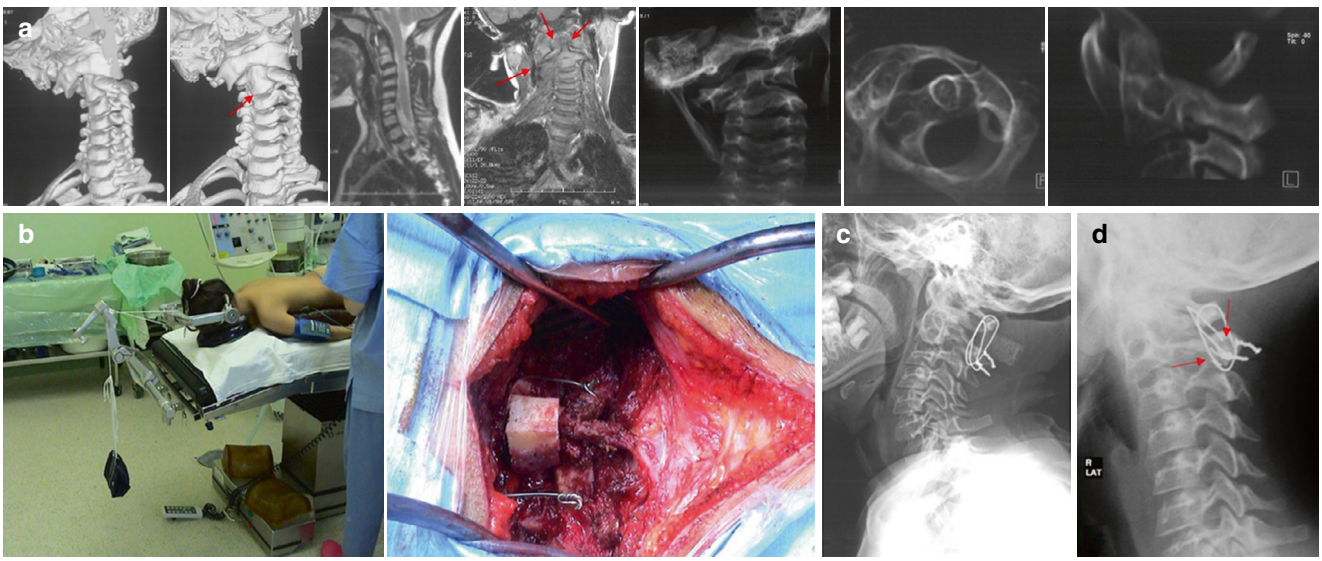


Fig. 14 A 9-year-old girl who had a bend in her neck. The last time she showed such a bent, she did not recover. (**a**) Atlanto axial rotatory dislocation and related torticollis were observed (Cock-robin position of head). (**b**) Stabilization was performed with wire and bone graft placed between C1-C2 vertebrae under traction. (**c**, **d**) Postoperative X-ray showing bone graft and wires holding C1-C2. At examination 6 months later, the bone graft has been resorbed and the wires are broken and loosened

for infection in this setting to develop strategies to reduce the incidence. Advanced age, high body mass index (BMI), diabetes, revision status, smoking, American Society of Anesthesiologists (ASA) score, chronic corticosteroid use/immunosuppression, and prior spinal instrumentation have all been reported as significant contributing factors. Beyond this, other factors may influence surgery, which affects outcomes: Active rheumatoid arthritis, dural tear, significant intraoperative bleeding, and prolonged surgical time are all high-risk factors for the development of an infection. If such a complication occurs, important clinical findings include redness, swelling, purulent discharge, and pain at the wound site. High fever, malaise, and weakness dominate the clinical picture. CRP, ESR, a complete blood cell count, and the differential will be informative, and a Gram stain of a wound swab and cultures are important steps to be taken. If an abscess is radiologically detected in a symptomatic patient, it should be drained. Limiting pharmacotherapy to targeted antibiotics and basing it on culture results with the use of broad-spectrum antibiotics are important until the culture results are available [33–37].

Case Study (Fig. 14) A 9-year-old girl repeatedly developed a "bulge in her neck" over the past 3 years without any

other clinical issues and returned to normal status within a few weeks each time. At presentation, she had this problem for 3 months without returning to normal. Antibiotic treatment was given, and some traction therapy was applied, but these had no success, and instead, she continued to complain of constant pain and had an abnormal neck posture. This patient had developed a secondary torticollis caused by a deep neck infection known as Grisel syndrome [38, 39], first described in 1930. Although its pathophysiology has not been fully understood, it appears that the nontraumatic dislocation of the atlantoaxial joint and rotational distortion (torticollis) occurs because of an infection or inflammation in the nasopharyngeal or otolaryngeal region. Clinically, a cock-robin wry position of the head is typical. This syndrome is a disease of childhood and is usually not seen after the age of 12. The treatment is conservative and includes the use of a cervical collar, analgesics, and antibiotics. Surgical intervention may rarely be required for patients who do not show that they benefit from conservative treatment. This can be a sequel of fibrosis that may develop in the atlantoaxial joint and that prevents the head from returning to its normal position. For this reason, the timing of the therapy is important. Once fibrosis has set in, the chances of a positive outcome after surgery decreases [22, 40].

Radiological examinations of our patient revealed persistent atlantoaxial rotatory dislocation after 2 weeks of conservative treatment. The rotatory misalignment can only temporarily be improved with traction, so we took the patient to surgery (under traction) and stabilized C1-C2 with wiring and bone grafting between the laminae of C1-C2.

Appendix

Anatomical Review

Upper Cervical Region Anatomy

This region consists of the flat occipital bone forming the posterior skull base, the clivus of the sphenoid bone anteriorly, and the C1 and C2 vertebrae. Instability at the craniocervical junction (CCJ) can arise from pathologies that develop in the C0-C1 and C1-C2 joints. The balance between stability and movement here is provided by strong ligaments. The craniocervical junction is stabilized anteriorly by five key ligaments: (1) the anterior atlantooccipital membrane (continues the anterior longitudinal ligament), (2) the tectorial membrane (continues the posterior longitudinal ligament), (3) the transverse ligament (provides attachment to the anterior arch of odontoid C1), (4) the alar ligament (connects the dense occipital condyles and axial rotation and adds resistance to lateral bending), and (5) the apical ligament (attaches the odontoid to the basion). The four structures that stabilize posteriorly are as follows: (1) the ligamentum nuchae, (2) the interspinous ligament, (3) the posterior atlantooccipital membrane, and (4) the ligamentum flavum and neck muscles (Fig. 15).

Neck muscles are multilayered and make serious contributions to stabilization. These muscles are divided into anterior, posterior, and lateral muscles. The posterior muscles are especially important when the cranium is to be firmly attached to the cervical region in some cases. These neck muscles and the muscles attached to the skull are stripped, and thus stabilization is performed. These muscles are then closed over the instrumentation area and sewn together. The better the muscles are preserved, the higher the chance of surgical success, as they will continue their stabilization duties.

The anterior neck muscles are a group of muscles that cover the front of the neck. They are further divided into the following subgroups: the superficial muscles, which are the most superficial in the anterior neck and include the platysma and sternocleidomastoid; the suprahyoid muscles, which as the name suggests, are located superior to the hyoid bone and include the digastric, mylohyoid, geniohyoid, and stylohyoid; and the infrahyoid muscles, which are located below the hyoid bone and consist of the sternohyoid, omohyoid, sternothyroid, and thyrohyoid.

The anterior vertebral muscles are a deep muscle group located just in front of the cervical vertebral column. These include the rectus capitis anterior, rectus capitis lateralis, longus capitis, and longus colli. These muscles are surrounded by the prevertebral fascia of the neck, so they are often referred to as the prevertebral muscles. The main function of these muscles is to provide varying degrees of flexion for the head.

The lateral neck muscles, also called the lateral vertebral muscles, are a group of muscles that run obliquely along the lateral sides of the neck. These include the anterior, middle, and posterior scalene muscles, which lie between the transverse processes of the cervical vertebrae and the upper two ribs. Because of their attachments, these muscles mainly produce ipsilateral flexion for the neck. They are related to neck movement rather than to the occipitocervical region.

The back of the neck is covered with the posterior group of muscles, which connect the skull to the spinal cord and pectoral girdle. These muscles can be divided into three layers: (1) the superficial layer, comprising the trapezius, splenius capitis, and splenius cervicis; (2) the deep layer, comprising the cervical transversospinalis

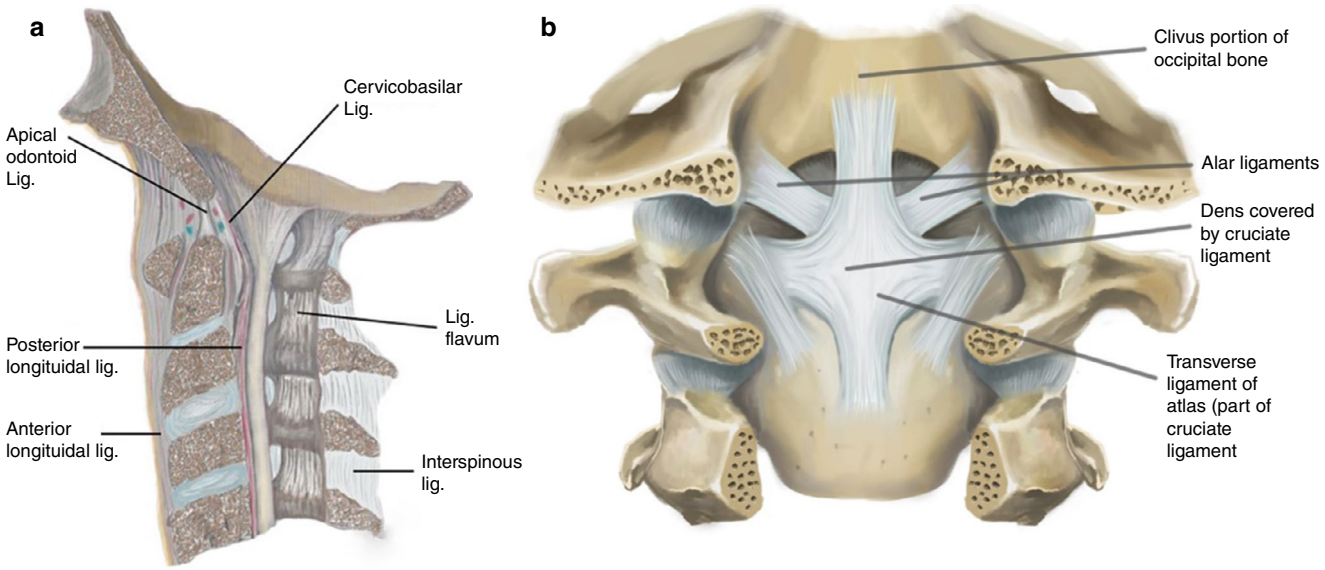


Fig. 15 (**a**) Occipitocervical region ligaments. (**b**) Cruciate ligament and alar ligaments connecting C1-C2-C3 are observed in the occipitocervical region. The accessory atlantoaxial ligament descends from both sides of the transverse ligament

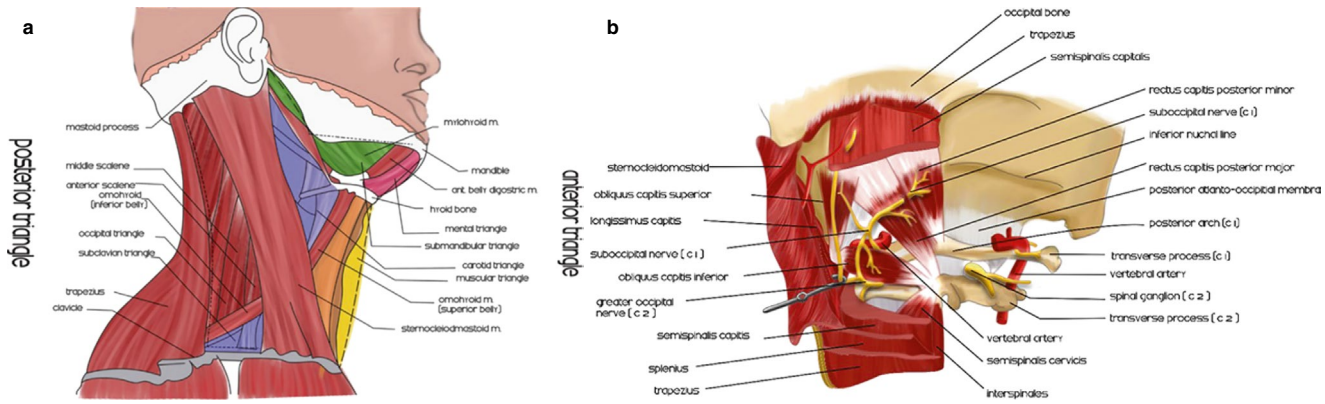


Fig. 16 (**a**) Deep and superficial neck muscles are seen. (**b**) Coronal section of deep and superficial muscles between cranium and cervical region

muscles (semispinalis capitis, semispinalis cervicis, and multifidus cervicis); and (3) the deepest layer, comprising the suboccipital muscles, interspinales cervicis muscles, and intertransversarii colli muscles (Fig. 16). Obviously, the overlapping layers effectively mix in stabilization while performing the flexion, extension, rotation, and bending movements of the neck.

Key Radiographic Metrics

Measurements of the Head in Neutral Position on the Cervical Spine

One fact to be pointed out is that cervical alignment is also affected by thoracic and lumbar pathologies, and as a result of pathologies occurring here, serious alignment disorders may occur. However, it especially causes the local deterioration of cervical alignment with cervical and occipitocervical pathologies. The alteration of normal cervical alignment as a result of pathology is the effort to keep the head level so that objects can continue to be seen in the horizontal plane. It is important in occipitocervical junction surgery in that if this alignment is not taken into account in a planned stabilization, any misalignment will end up as a permanent deformity that seriously disturbs forward gaze and that can seriously compromise the patient's gait (and thus mobility). Therefore, surgeons must ensure that the cervical alignment stays in the proper plane before any planned instrumentation (Fig. 17).

Important radiographic morphometric parameters are listed in the Appendix, which explains their relevance for the occipi-

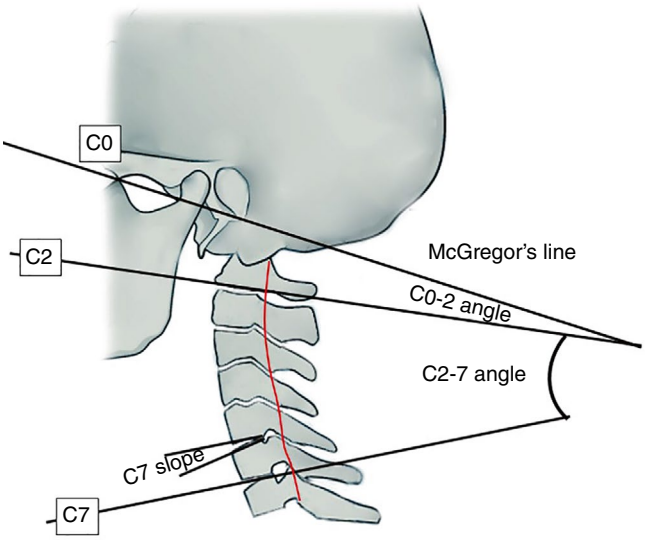


Fig. 17 C0-C2 angle and C7 slop angle measurements

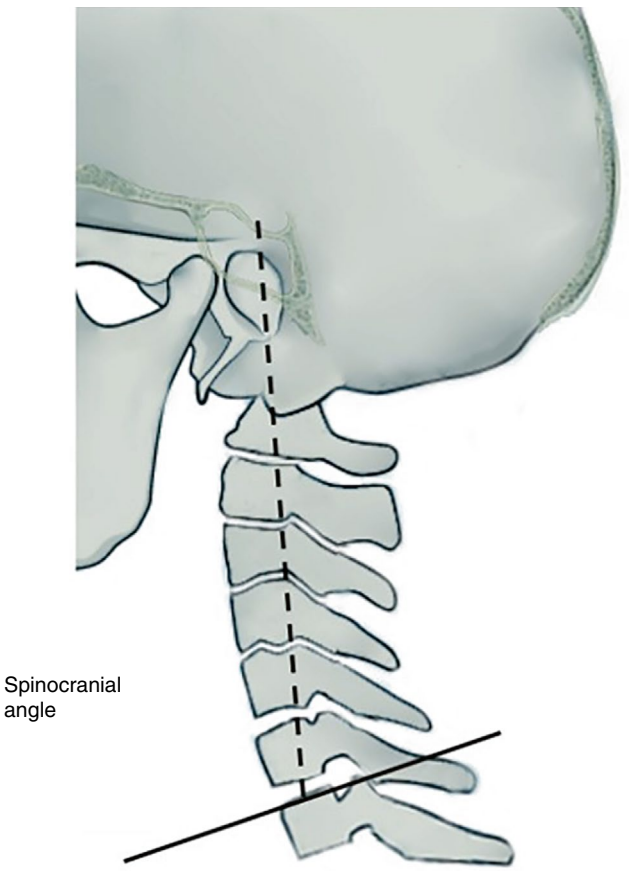


Fig. 18 Spinocranial angle. This is the angle between the line passing the upper border of the C7 vertebra body tangentially and the line drawn from the midpoint of C7 to the sella turcica. It gives the position of the head on C7-T1 and shows whether it is in sagittal balance

tocervical region. After any surgery, staying within the normative morphometric values is necessary to maintain the patient's visual perspective and to allow the head to have a healthy relationship with the remaining parameters of the spine (Fig. 18).

Measurements in the Occipitocervical Region

Anatomical markers constitute important parameters for occipitocervical craniometry. Such craniometry has been defined for conventional radiography, CT, and MRI. Measurements such as the Chamberlain, McGregor, McRae, and Wackenheim line formally describe the relationship between the cranium and the cervical region. While extremely helpful in diagnosis, knowing these measures and others (e.g., the atlantodental interval, ADI, power ratio, Harris rule, and clivoaxial angle) will also guide the planning of the surgery to be performed. Therefore, these basic measurements should be kept in mind.

Chamberlain Line: This measure is the line connecting the back of the hard palate with the opisthion, as seen in the lateral view of the craniocervical junction. Basilar invagination can be identified when the tip of the odontoid is >3 mm above this line (Fig. 19).

McGregor Line: This measure refers to a line connecting the posterior edge of the hard palate to the most caudal point of the occipital curve. An odontoid tip 4.5 mm above this line is indicative of basilar invagination.

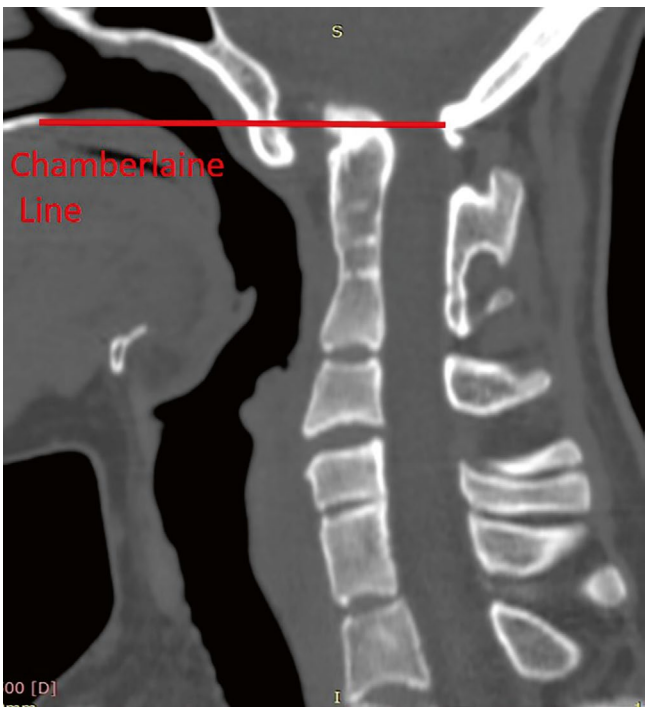


Fig. 19 Odontoid type I invagination appears above the Chamberlain line

McRae Line: A radiographic line drawn on a lateral skull radiograph or midsagittal section of CT or MRI connecting the anterior and posterior margins of the foramen magnum (basion to opisthion). It assesses the presence of basilar invagination (atlantoaxial impaction). The tip of the odontoid process is normally located about 5 mm below this line; basilar invagination is diagnosed when the odontoid tip crosses this line. The line also helps to measure the position and degree of cerebellar tonsillar descent since the cerebellar tonsils are normally found above this line, namely the foramen magnum. In cases of cerebellar ectopia with a caudal displacement of the tonsils >5 mm below the foramen magnum, a Chiari malformation may be diagnosed.

Wackenheim Line: This measure is also known as the clivus-canal line or the basilar line. It is created by drawing a line along the clivus and extending it below and into the upper cervical canal on a midsagittal view. Normally, the tip of the odontoid is ventral (anterior) to this line, and the tip of the odontoid is touching the line (tangential). In cases of basilar invagination, this line cuts through the odontoid. In posterior atlantooccipital dislocation, the line will extend behind the odontoid process.

Atlantodental Interval (ADI)

This measure is used to assess ligamentous stability at the C1/C2 junction, as seen on a lateral or axial view (plain X-ray or sagittal CT cut), and it aids in the diagnosis of atlantooccipital dissociation injuries and of isolated atlas and axis injuries, which can best be measured as the horizontal distance between the anterior arch of the atlas and the odontoid process of C2. It is the distance between the posterior cortex of the anterior arch of the atlas and the anterior cortex of the odontoid in the median (midsagittal) plane. On X-ray, its normal values are <3 mm in adults, <3 mm in men, < 2.5 mm in women, and <5 mm in children (regardless of sex). On CT, this distance is <2 mm in adults.

$$\textbf{Powers ratio} = C - D / A - B$$

C-D: Distance from the basion to the arch of posterior C1.

A-B: Distance from the anterior arch of C1 to the opisthion.

Importantly, if the ratio is ~1, it is considered normal. If the ratio is >1.0, there is a possibility of anterior dislocation. Conversely, if the ratio is <1.0, there is a probability of posterior atlantooccipital dislocation. With respect to the underlying pathology, there is a possibility of a fracture of the odontoid or a fracture of the atlas arch (Fig. 20).

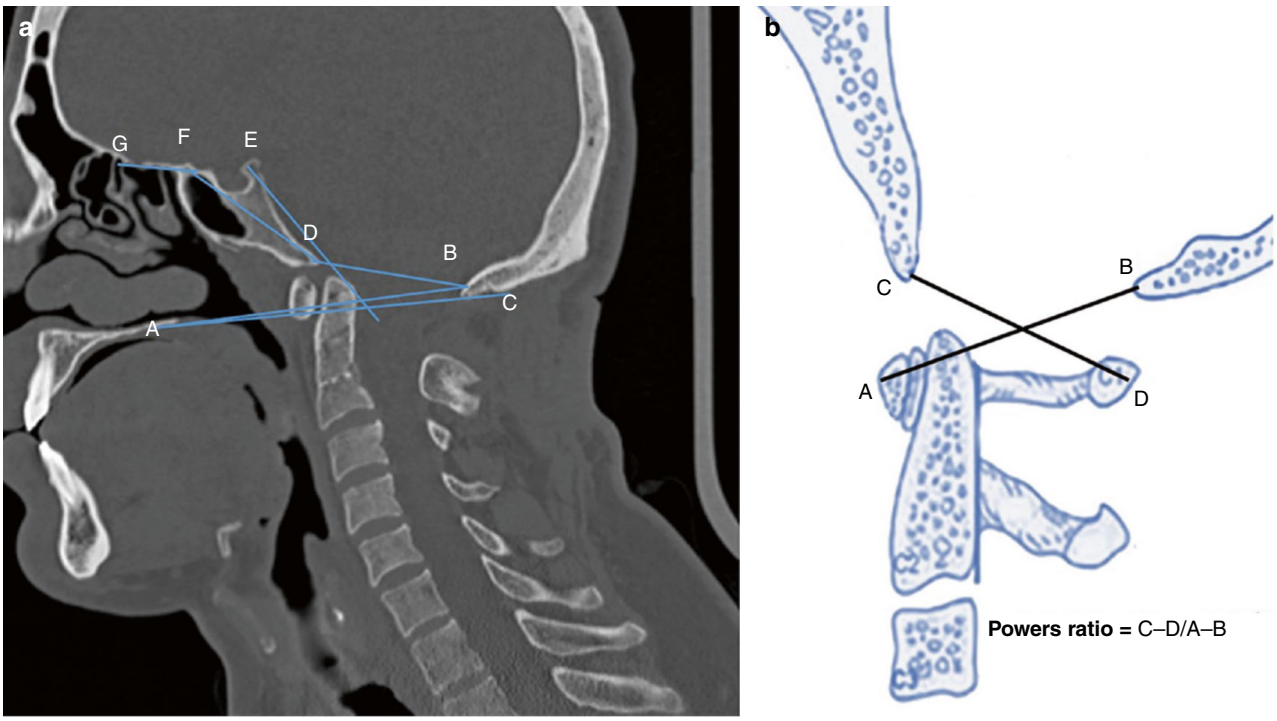


Fig. 20 (**a**) Parameters revealing the relationship between the cranium and occipitocervical region. AB Chamberlain line, AC McGregor line, DB McRae line, ED Wackenheim Clivus line. (**b**) Power's ratio is around 1. If it is >1, the dislocation is considered anterior; if <1, it is considered posterior

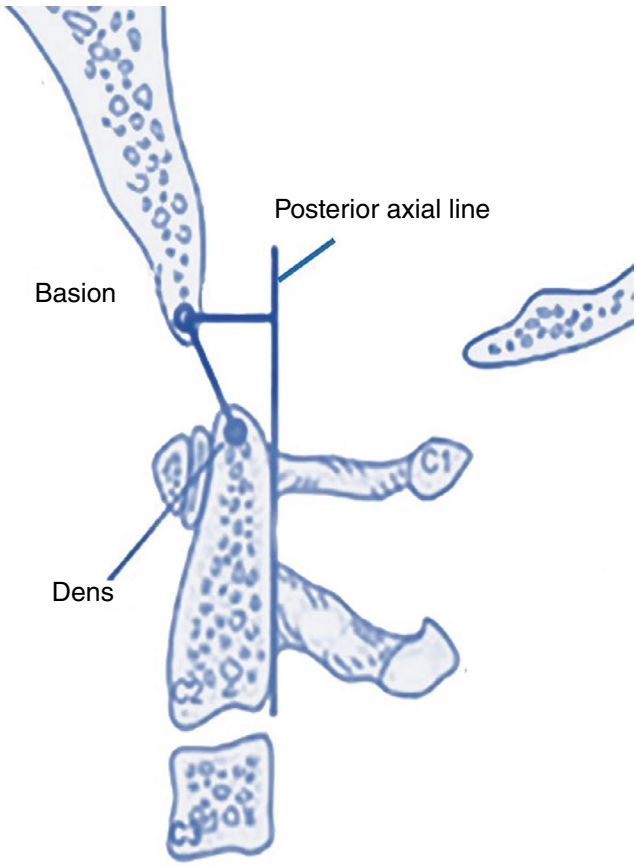


Fig. 21 Harris rule of 12: basion–dens interval or basion–posterior axial interval > 12 mm suggests occipitocervical dissociation

Harris Rule of 12

Occipitocervical dissociation is considered if the distance of the basion–dens measure (BDM) or the basion–axial measure (BAM) is >12 mm (Fig. 21). The clivoaxial angle is measured by drawing a line along the posterior (back—or, when lying more horizontally, the top) side of the lower clivus and intersecting that line with a line drawn on the posterior side of the axis. If the angle created is less than 135°, it is considered pathological. Like instability, a kyphotic clivoaxial angle is often seen in patients with connective tissue disorders and degenerative rheumatoid diseases (Fig. 22).

Further Important Parameters and their Relevance to the Occipitocervical Region

High C0-C2 Angle (High Cervical Angulation): This is the angle formed between the line starting from the end point of the bone projection of the upper palate and passing through the lowest part of the occipital bone (McGregor line) and a second line passing through the lower edge of C2. Its mean value is 15.8° (+7.15°), and it is always lordotic.

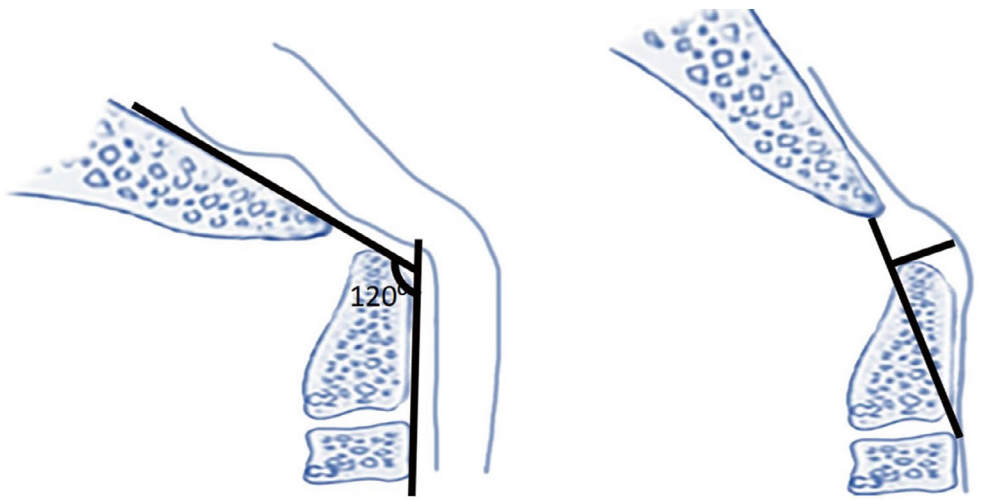


Fig. 22 The clivoaxial angle is formed by a line extrapolation at the posterior end of the lower clivus that intersects with a line drawn on the posterior side of the axis. If the enclosed angle created is less than 135°, it is considered pathological

Cervical Lordosis Angle: This is the angle between the tangential line passing through the lower face of the C2 vertebra and the perpendicular lines drawn to the tangential lines passing through the lower face of the C7 vertebra (the Cobb method). The average value is 30.73° ± 4.88°.

Spinocranial Angle (SCA): This is the angle between the tangential line passing through the upper edge of the C7 vertebral body and the line drawn from the midpoint of C7 to the sella turcica on this line. In asymptomatic people, the value of this angle is 83° ± 9°, on average. It is an important angle because it establishes the position of the head on C7-T1 and tells the observer whether the head is in good sagittal balance.

References

1. Ahmed R, Menezes AH. Management of operative complications related to occipitocervical instrumentation. Neurosurgery. 2013;72(2 Suppl Operative):ons214-28.
2. Bono CM, Vaccaro AR, Fehlings M, Fisher C, Dvorak M, Ludwig S, Harrop J. Spine trauma study group. Measurement techniques for upper cervical spine injuries: consensus statement of the spine trauma study group. Spine (Phila Pa 1976). 2007;32(5):593–600.
3. Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. Spine (Phila Pa 1976). 2001;26(22):2467–71.
4. He B, Yan L, Xu Z, Chang Z, Hao D. The causes and treatment strategies for the postoperative complications of occipitocervical fusion: a 316 cases retrospective analysis. Eur Spine J. 2014;23(8):1720–4.
5. Hwang SW, Gressot LV, Chern JJ, Relyea K, Jea A. Complications of occipital screw placement for occipitocervical fusion in children. J Neurosurg Pediatr. 2012;9(6):586–93.
6. Le Huec JC, Thompson W, Mohsinaly Y, Barrey C, Faundez A. Sagittal balance of the spine. Eur Spine J. 2019;28(9):1889–905.
7. Mazur MD, Sivakumar W, Riva-Cambrin J, Jones J, Brockmeyer DL. Avoiding early complications and reoperation during occipitocervical fusion in pediatric patients. J Neurosurg Pediatr. 2014;14(5):465–75.
8. Yang D, Patel S, DiSilvestro K, Li N, Daniels A. Postoperative complication rates and hazards-model survival analysis of revision surgery following Occipitocervical and Atlanto-axial fusion. N Am Spine Soc J. 2020;3:100017.
9. Ankith NV, Avinash M, Srivijayanand KS, Shetty AP, Kanna RM, Rajasekaran S. Congenital osseous anomalies of the cervical spine: occurrence, morphological characteristics, embryological basis and clinical significance: a computed tomography based study. Asian Spine J. 2019;13(4):535–43.
10. Browd S, Healy LJ, Dobie G, Johnson JT 3rd, Jones GM, Rodriguez LF, Brockmeyer DL. Morphometric and qualitative analysis of congenital occipitocervical instability in children: implications for patients with Down syndrome. J Neurosurg. 2006;105(1 Suppl):50–4.
11. Dabaghi-Richerand A, Hensinger R, Farley F. Congenital disorders of the child's cervical spine. 2018 https://doi.org/10.1007/978-1-4939-7491-7-9.
12. Klimo P Jr, Rao G, Brockmeyer D. Congenital anomalies of the cervical spine. Neurosurg Clin N Am. 2007;18(3):463–78.
13. Rojas CA, Hayes A, Bertozzi JC, Guidi C, Martinez CR. Evaluation of the C1-C2 articulation on MDCT in healthy children and young adults. AJR Am J Roentgenol. 2009;193(5):1388–92.
14. Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. Acta Neurochir. 1994;129:47–53.
15. Guo J, Lu W, Ji X, Ren X, Tang X, Zhao Z, Hu H, Song T, Du Y, Li J, Shao C, Xu T, Xi Y. Surgical treatment of atlantoaxial subluxation by intraoperative skull traction and C1-C2 fixation. BMC Musculoskelet Disord. 2020;21(1):239.
16. Menezes AH, Ryken TC. Craniovertebral junction abnormalities. In: Weinstein SL, editor. The pediatric spine: principles and practice, 1st edn, vol. 1. New York: Raven Press; 1994. p. 307–21.
17. Menezes AH, VanGilder JC. Anomalies of the craniovertebral junction. In: Youmans J, editor. Neurological surgery, 3rd edn, vol. 2. Philadelphia: Saunders; 1990. p. 1359–420.
18. Salunke P, Sharma M, Sodhi HB, Mukherjee KK, Khandelwal NK. Congenital atlantoaxial dislocation: a dynamic process and role of facets in irreducibility. J Neurosurg Spine. 2011;15(6):678–85.
19. Yang SY, Boniello AJ, Poorman CE, Chang AL, Wang S, Passias PG. A review of the diagnosis and treatment of atlantoaxial dislocations. Global Spine J. 2014;4(3):197–210.
20. Goel A. Goel's classification of atlantoaxial "facetal" dislocation. J Craniovertebr Junction Spine. 2014;5(1):3–8.
21. Magerl F, Seemann P. Stable posterior fusion of the atlas and axis by transarticular screw fixation. In: Society CSR, editor. Cervical spine. New York: Springer-Verlag; 1986. p. 322–7.
22. Ozer AF, Marandi HJ, Sasani M, Oktenoglu T, Suzer T. Posttraumatic syringomyelia: a technical note. Turk Neurosurg. 2014;24(4):618–22.
23. Henderson FC. Cranio-cervical instability in patients with hypermobility connective disorders. J Spine. 2016;2016(5):2D.
24. Lustrin ES, Karakas SP, Ortiz AO, Cinnamon J, Castillo M, Vaheesan K, Brown JH, Diamond AS, Black K, Singh S. Pediatric cervical spine: normal anatomy, variants, and trauma. Radiographics. 2003;23(3):539–60.
25. Reynolds MD. Lateral subluxation of atlanto—axial joint. Ann Rheum Dis. 1979;38(5):499.
26. Fielding JW, Hawkins RJ. Atlanto-axial rotatory fixation. (fixed rotatory subluxation of the atlanto-axial joint). J Bone Joint Surg Am. 1977;59(1):37–44.
27. Riascos R, Bonfante E, Cotes C, Guirguis M, Hakimelahi R, West C. Imaging of Atlanto-occipital and atlantoaxial traumatic injuries: what the radiologist needs to know. Radiographics. 2015;35(7):2121–34.
28. Shin H, Barrenechea IJ, Lesser J, Sen C, Perin NI. Occipitocervical fusion after resection of craniovertebral junction tumors. J Neurosurg Spine. 2006;4(2):137–44.
29. Oh YG, Lee BJ, Jeon SR, Roh SW, Rhim SC, Park JH. Anterior odontoid screw fixation for the treatment of type 2 odontoid fracture with a kyphotic angulation or an anterior Down-slope: a technical note. Neurol Med Chir (Tokyo). 2019;59(8):321–5.
30. Fei Q, Li J, Lin J, Li D, Wang B, Meng H, Wang Q, Su N, Yang Y. Risk factors for surgical site infection after spinal surgery: a meta-analysis. World Neurosurg. 2016;95:507–15.
31. Ogihara S, Yamazaki T, Inanami H, Oka H, Maruyama T, Miyoshi K, Takano Y, Chikuda H, Azuma S, Kawamura N, Yamakawa K, Hara N, Oshima Y, Morii J, Okazaki R, Takeshita Y, Tanaka S, Saita K. Risk factors for surgical site infection after lumbar laminectomy and/or discectomy for degenerative diseases in adults: a prospective

multicenter surveillance study with registry of 4027 cases. PLoS One. 2018;13(10):e0205539.
32. Olsen MA, Mayfield J, Lauryssen C, Polish LB, Jones M, Vest J, Fraser VJ. Risk factors for surgical site infection in spinal surgery. J Neurosurg. 2003;98(2 Suppl):149–55.
33. Huckell CB, Buchowski JM, Richardson WJ, Williams D, Kostuik JP. Functional outcome of plate fusions for disorders of the occipitocervical junction. Clin Orthop Relat Res. 1999;359:136–45.
34. Lee CC, Liu YT. Occipitocervical fusion complicated with cerebellar abscess: a case report. BMC Musculoskelet Disord. 2020;21:129.
35. Nockels RP, Shaffrey CI, Kanter AS, Azeem S, York JE. Occipitocervical fusion with rigid internal fixation: long-term follow-up data in 69 patients. J Neurosurg Spine. 2007;7(2):117–23.
36. Ogihara S, Yamazaki T, Shiibashi M, Chikuda H, Maruyama T, Miyoshi K, Inanami H, Oshima Y, Azuma S, Kawamura N, Yamakawa K, Hara N, Morii J, Okazaki R, Takeshita Y, Nishimoto J, Tanaka S, Saita K. Risk factors for deep surgical site infection after posterior cervical spine surgery in adults: a multicentre observational cohort study. Sci Rep. 2021;11(1):7519.
37. Pharisa C, Lutz N, Roback MG, Gehri M. Neck complaints in the pediatric emergency department: a consecutive case series of 170 children. Pediatr Emerg Care. 2009;25:823–6.
38. Blankstein A, Pavlotsky F, Roizin H, Ganel A, Chechick A. Acquired torticollis in hospitalized children. Harefuah. 1997;133:616–9.
39. Iaccarino C, Francesca O, Piero S, Monica R, Armando R, de Bonis P, Ferdinando A, Trapella G, Mongardi L, Cavallo M, Giuseppe C, Franco S. Grisel's syndrome: non-traumatic atlantoaxial rotatory subluxation-report of five cases and review of the literature. Acta Neurochir Suppl. 2019;125:279–88.
40. Viscone A, Brembilla C, Gotti G. The importance and effectiveness of conservative treatment in Grisel's syndrome. J Pediatr Neurosci. 2014;9(2):200–1.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

