Arnold-Chiari Syndrome – a review

Agnieszka Pociecha

Silesian Women's Health Center in Katowice, 6 Kotlarz Street, 40-139 Katowice,

Polande-mail: pociechaagnieszka15@gmail.com

ORCID: https://orcid.org/0009-0001-6879-1107

Marta Kozikowska

Upper-Silesian Medical Center in Katowice, 45 Ziołowa Street, 40-635 Katowice,

Polande-mail:marta669@onet.eu

ORCID: https://orcid.org/0000-0002-5054-9187

Bożena Kmak

District Railway Hospital in Katowice, Medical University of Silesia, 65 Panewnicka Street,40-760 Katowice, Poland

e-mail: bozena.kmak@wp.pl

ORCID: https://orcid.org/0000-0003-2112-4910

Anna Szot

Medical University of Silesia in Katowice, 18 Medyków Street, 40-752 Katowice,

Polande-mail: anna.szot1201@gmail.com

ORCID: https://orcid.org/0009-0002-7732-150X

Magdalena Górska

District Railway Hospital in Katowice, Medical University of Silesia, 65 Panewnicka Street,40-760 Katowice, Poland

e-mail: magdag6606@gmail.com

ORCID: https://orcid.org/0009-0009-2691-8278

Nikola Stuglik

Medical University of Silesia in Katowice, 18 Medyków Street, 40-752 Katowice,

Polande-mail: nikolastuglik4@gmail.com

ORCID: https://orcid.org/0009-0009-8262-8478

Anna Hitnarowicz

Provincial Hospital in Opole, 53 Kośnego Street, 45-372 Opole,

Polande-mail: hitwicz98@wp.pl

ORCID: https://orcid.org/0000-0003-2364-0839

Aleksandra Janocha

Independent Public Health Care Center number 1 in Rzeszów, 4 Rycerska Street, 35-241 Rzeszow, Poland

e-mail: janocha.aleksandra@gmail.com

ORCID: https://orcid.org/0000-0002-1350-991X

Aneta Jerzak

Ludwik Rydygier Specialist Hospital in Krakow, 1 Złotej Jesieni Estate, 31-826 Krakow, Poland

e-mail: aneta.jerzak1@gmail.com

ORCID: https://orcid.org/0009-0004-4658-2146

Abstract

Arnold Chiari syndrome, also known as Chiari malformation, is a group of deformations of the posterior cranial fossa and hindbrain, consisting in the lowering of the cerebellum or its tonsils towards the occipital foramen. This leads to a reduction in the volume reserve within the foramen magnum, pressure on surrounding structures and obstruction of the flow of cerebrospinal fluid. The process is most often asymptomatic. Symptoms include headaches, neck pain, but also fainting, sinus bradycardia, coordination disorders and many others. Chiari malformation is often diagnosed incidentally. The basis of diagnosis is the detection of characteristic morphological features in magnetic resonance imaging. Surgical treatment is successfully used among patients with severe Arnold-Chiari syndrome and progression of clinical symptoms.

Materials and methods

Literature included in the PubMed, BioMed Central and Polish Medical Platform databases searched by means of the words such as Gamma Knife, CyberKnife, radiosurgery, stereotactic radiotherapy. Sources quoted in selected works were also used.

Summary

Arnold-Chiari malformation is often discovered incidentally. If the features observed on MRI suggest the above diagnosis, the patient should be referred to a neurologist. After excluding other possible causes of the imaged morphological features and performing a dedicated magnetic resonance imaging examination, the neurosurgeon decides whether to qualify for the procedure. In a selected group of patients, significant improvement can be expected after surgical treatment.

Keywords: Arnold-Chiari syndrome, cerebellum, decompression

Introduction

At the end of the 19th century, Julius Arnold and Hans Chiari described a disease in the posterior cranial fossa involving deformation of the cerebellum and brainstem in children. Currently, Arnold-Chiari malformation is defined as a set of hindbrain pathologies thatconsists of the displacement of cerebellar structures, most often the tonsils, through the foramen magnum of the skull into the cervical spinal canal [1]. Possible defects include herniation of the cerebellar tonsils through the foramen magnum, complete absence of the cerebellum, or other intra- and extracranial defects, such as hydrocephalus, syringomyelia, encephalocele, or other dysrapheias [2]. The disease affects the cerebellum, brainstem, skull base and cervical spinal cord. It is one of the most common defects of the craniocervical junction in adults [1].

Classification

Based on the morphology and advancement of anatomical defects visible in imaging tests, there are four types:malformation Chiariego [2].

Variant I has the mildest course and occurs most frequently (approximately 1/1000 births) [2, 3]. Clinically, this type is characterized by an asymptomatic course. It may also manifest itself in the form of neck pain, headaches or other focal neurological symptoms in late childhood or adulthood. It is often detected accidentally [1]. The diagnosis is made based on the morphology shown in imaging tests. It is characterized by the depression of one or two pointed cerebellar tonsils by more than 5 mm below the foramen magnum, i.e. below McRae's line, measured from the midpoint of the anterior border of the foramen magnum (basion) to the midpoint of the posterior border of the foramen magnum (opisthion) [2].Among children presenting at an early stage it may be less than 3 mm [4].

Type II Arnold-Chiari syndrome consists of brainstem herniation, elongated cerebellum with tonsillar depression and cerebellar vermis, which may be caused by open distal dysraphism or myelomeningocele [2].

Variant III includes hindbrain herniation in the form of a low occipital or high cervical cerebrospinal hernia with serious consequences for the development of the nervous system. [2].

Type IV is currently considered obsolete and practically not used [5]. This was a controversial and very rare variant that was characterized by severe cerebellar hypoplasia, similar to its primary agenesis. Some claimed that it may coexist with myelomeningocele, while others believed that the presence of myelomeningocele should classify Arnold-Chiari syndrome as type II with atrophic cerebellum [6, 7].

There are also other controversial types of malformation Chiari disease, including types 0, 1.5, and V. Variant 0 is described as syringomyelia without hindbrain herniation, type 1.5 seemed to be a progression of I, with a greater degree of depression of the cerebellar tonsils,

with involvement of the brainstem [8]. The most severe type V presented with cerebellar agenesis with depression of the occipital lobe and herniation through the foramen magnum [9].

Epidemiology

Arnold-Chiari syndrome, type I is the most common of all variants - approximately 1 in 1,000 births, with a slight predominance of women (female to male ratio of 1.3:1) [3]. It occurs in approximately 0.5-3.5% of the general population [2]. Epidemiological data are probably underestimated because the course is often asymptomatic or becomes apparent only in adulthood. Based on neuroimaging data, it is estimated that this malformation may occur with a frequency of 1% in the pediatric population [10].

Type II occurs with a frequency of 0.44/1000 births. The disease occurs much less frequently thanks to folic acid supplementation by pregnant women.

Other variants of Arnold-Chiari syndrome occur much less frequently. The most common of them is type III, accounting for 1-4.5% of all cases of Chiari malformation [2].

Etiology

There are many proposed theories regarding the etiology malformation Chiari, including mechanical, hydrodynamic and molecular theory [11].

Arnold-Chiari syndrome type I may be a secondary pathology to diseases of the skull base, such as craniosynostosis, craniocerebral disproportion, deformities of the child's head, such as plagiocephaly, or bone metabolism disorders. A reduction in the volume of the posterior cranial fossa leads to the displacement of the cerebellar tonsils through the foramen magnum. The causes also include bone defects within the craniocervical junction, instability of the atlantoaxial joint, and occipital-axial hypermobility [12, 13]. In practice, however, this applies to a very small proportion of patients.

Type I may also arise under the influence of increasing cerebrospinal fluid pressure in the case of idiopathic intracranial hypertension, hydrocephalus or brain tumor [14].

Intracranial hypotension, which may occur spontaneously due to idiopathic cerebrospinal fluid leakage or as a result of iatrogenic lumbar-peritoneal leakage (e.g. through a fistula resulting from spine surgery), may be the source of ectopia of the cerebellar tonsils [14]. Iatrogenic Arnold-Chiari syndrome type I has been observed as a result of lumboperitoneal shunt implantation in the treatment of idiopathic intracranial hypertension [15].

The downward displacement of the cerebellar tonsils through the foramen magnum may be the result of traction by the terminal cord during anchoring of the spinal cord [16].

Traditionally, Arnold-Chiari syndrome has been described as a developmental defect, which may indicate a genetic basis, but there is little evidence for this. Moreover, it is rarely detected in newborns or infants, and familial accumulation is rare [14]. Some sources state that the cause may be changes in chromosomes 2, 9, 14 and 15 [17, 18, 19]. A mutation of the NKX2-1 gene (14q13.3), encoding a protein involved in the formation of forebrain structures during the early stage of embryogenesis, was identified in a girl suffering from Arnold-Chiari I syndrome [20]. Another potential mutation concerns the EPAS1 gene (2p21) encoding hypoxia-inducible factor (HIF-2α), which is involved in endochondral and endothelial ossification [21]. These genetic disorders probably destabilize the development of the paraxial mesoderm, resulting in the loss of the volume reserve of the posterior cranial fossa, foramen magnum and the upper part of the cervical canal [1, 22]. Mutations within chromosomes 1 and 22 have also been described as possible causes of hereditary hypoplasia of the posterior cranial fossa [23].

McClone and Knepper proposed the theory that an open neural tube defect (myelomeningocele) is the underlying cause of malformation Chiari type II [24]. It leads to leakage or redirection of the flow of cerebrospinal fluid, which significantly exceeds the volume reserve of the fourth ventricle. Excessive pressure in it causes hypoplasia of the posterior cranial fossa and herniation of the cerebellar tonsils even during fetal life. This is also a possible cause of the development of type III Arnold-Chiari syndrome. Folic acid deficiency and methylenetetrahydrofolate reductase mutations increase the risk of neural tube defects and therefore may also predispose to the development of variants I and II of the malformation [2].

The etiology of the mentioned types of Arnold-Chiari syndrome is still a matter of debate and is not fully understood. Trauma may be the source of herniation of the cerebellar tonsils, although if the posterior cranial fossa is of normal size, the diagnosis of Arnold-Chiari syndrome is inappropriate [2].

Pathophysiology

Among patients with Arnold-Chiari syndrome type I, the skull bones are often underdeveloped, resulting in a reduced volume reserve of the posterior cranial fossa that is unable to accommodate the entire cerebellum. The consequence of this is the displacement of the cerebellar tonsils through the foramen magnum of the skull [2]. The main cause of the pathology is direct pressure of the ectopically located cerebellar tonsils on the neurological structures within the occipital foramen and its vicinity, as well as obstruction of the outflow of cerebrospinal fluid. This pathology may be accompanied by syringomyelia, which is a myelopathy involving the formation of abnormal fissures or cavities filled with cerebrospinal fluid within the spinal cord, most often in the cervical or thoracic spine.

The volume of the posterior cranial fossa in type II malformation of the Chiari function is significantly smaller than in type I. The cerebrospinal fluid reservoirs are poorly developed

due to the lack of expansion of the fourth ventricle, which is a consequence of pathological changes in the cerebrospinal fluid circulation and even neural tube defect during fetal life. All this is the source of the downward displacement of hindbrain structures and their pressure on the foramen magnum [25].

In both types I and II, there is obstruction of cerebrospinal fluid flow, enlargement of the fourth ventricle and pressure on the occipital foramen, which over time may lead to increased intracranial pressure, development of hydrocephalus (10% of patients) and syringomyelia [2].

Clinical symptoms

Patients with Arnold-Chiari syndrome type 1 are usually asymptomatic. The most common symptoms, both among children and adults, are neck pain and headache [26]. It is a so-called mechanically triggered headache resulting from blockage of cerebrospinal fluid flow and ectopy of the cerebellar tonsils. It is intensified by neck extension and flexion, but also by coughing, sneezing and other situations when the abdominal press is used. This pain begins in the occipital area, then radiates to the parietal area, and then is felt throughout the head [14].

Due to the reduced volume reserve of the foramen magnum, headaches intensify during the Valsalva maneuver, which differentiates them from chronic headaches, which in turn may occur in the course of idiopathic intracranial hypertension [27]. Unlike migraine headaches, those occurring in the course of Arnold-Chiari syndrome are characterized by earlier onset and greater severity [28].

In addition to neck and head pain, Chiari I may also manifest itself in the form of other symptoms resulting from direct compression of the brain stem, which causes autonomic dysfunction in the form of episodes of syncope or sinus bradycardia [29]. Scoliosis, which occurs mainly among children, is structural in nature. It is caused by syringomyelia, although recent research suggests that there is no relationship between the severity of scoliosis and the size of the fissure in the spinal cord.

Other symptoms may include swallowing problems, vomiting, dizziness, problems with coordination, sensory symptoms such as numbness, tingling in the limbs. Nausea,tinnitus, and progressive weakness of the muscles of the arms and legs also occur. Stiffness of the joints, shoulders, arms or legs, and impaired bladder and bowel function represent clinicalsymptoms of syringomyelia. Sensory and motor symptoms of the limbs, which are a direct result of compression of the medulla oblongata within the foramen magnum, are quite rare, even in the case of its marked stenosis or extensive syringomyelia. Nystagmus may be a less specific, but possible symptom, especially when Arnold-Chiari syndrome coexists with syringomyelia [1].

Clinical symptoms among children differ from those in adults. In a very young population, symptoms such as headaches or neck pain are very difficult to observe. They manifest

themselves mainly as tearfulness, irritability and developmental disorders [30]. Pediatric patients are much more likely to experience brain stem dysfunction, sleep apnea, or feeding difficulties [31]. The last of these symptoms results from impaired function of the glossopharyngeal and vagus nerves, which results in the absence of the vomiting reflex and hoarseness [32]. Due to the involvement of the cerebellum in higher cognitive functions, it has also been observed that patients with Arnold-Chiari syndrome may experience abnormalities in executive functioning, verbal fluency, spatial orientation and memory processing [33].

Diagnostics

Arnold-Chiari syndrome, especially type I, is often detected quite accidentally during an MRI examination performed for other health reasons. The significance of identified morphological symptoms should always be verified by a neurologist [14].

Magnetic resonance imaging is the main and preferred imaging test used in the diagnosis of Arnold-Chiari syndrome. It provides information for the anatomy of the craniocervical junction and allows the identification of complications such as hydrocephalus or syringomyelia [34]. It reveals the depression of the cerebellar tonsils as well as their pointed or elongated shape, both in asymptomatic patients and those with clinical symptoms, and the greater the degree of depression of the cerebellar tonsils, the greater the probability that the patient is symptomatic [35, 36].

The diagnostic criterion was ectopia of the cerebellar tonsils greater than 5 mm below the level of the foramen magnum, i.e. below the McRae line. At the time of diagnosis, 50% of patients also have syringomyelia and cystic dilatation of the central canal of the spinal cord. The extent of these pathologies can range from a small segment of the medulla to anelongated syringomyelia. There are many theories about the development of syringomyelia inthe course of Arnold-Chiari malformation, but not all aspects of this issue have been well explained so far. Other pathologies that can be detected in MRI and coexistent with Chiari malformation include skeletal anomalies within the craniocervical junction, scoliosis or intraspinal lipomas [14].

The most beneficial option is to perform an MRI of the head with additional sequences sensitive to the flow of cerebrospinal fluid, as well as an MRI of the entire spine to exclude syringomyelia and other spinal cord diseases. It is incorrect to qualify a patient for the procedure based on the morphological features visible in the MRI examination, includingonly the head or only the neck [14].

In case of contraindications or inability to perform MRI, it is possible to use methods such as CT myelography, non-contrast CT, X-ray of the skull and cervical spine [1]. Computed tomography is also performed when bony abnormalities in the craniocervical junction are suspected [14].

Laboratory tests are not used in the diagnosis of Arnold-Chiari syndrome, however, all preoperative tests require appropriate initial tests, such as a complete blood count, electrolytes and metabolites, chest X-ray and electrocardiography. Other useful tests include polysomnography, videofluoroscopic examination of the swallowing mechanism, examination of auditory evoked potentials from the brainstem, and examination of somatosensory evoked potentials [1].

Prenatal diagnosis of Arnold-Chiari syndrome with coexisting syringomyelia has also been described [37].

Treatment

Due to the lack of strictly defined guidelines and a precise algorithm for the treatment of Arnold-Chiari syndrome, treatment is based on a strategy combining conservative and surgical procedures, depending on the patient's clinical condition [1].

The role of pharmacotherapy in Arnold-Chiari syndrome is limited and focused primarily on alleviating symptoms such as headaches or neck pain. Non-steroidal anti-inflammatory drugs, myorelaxants or cervical spine support collars may provide relief. However, these options do not provide sufficient improvement in less common, more serious ailments, such as coordination, gait, swallowing disorders and many others [1].

Surgical treatment is used in patients who present a severe form with progressive symptoms. It is necessary to confirm the depression of the cerebellar tonsils by imaging and the blockage of cerebrospinal fluid flow by cine-MR imaging.

In the case of type I malformation, where the main problem is compression within the foramen magnum by ectopically located cerebellar tonsils, the most frequently used procedure is occipital decompression, also known as craniocervical decompression [1, 14]. Itsaim is to reduce the pressure on the medulla oblongata and provide better spatial conditions in this area, enabling proper flow of cerebrospinal fluid [1]. The procedure involves performing a suboccipital craniectomy, above the foramen magnum, at the level of the C1 posterior arch (C1/C2 laminectomy) with or without duraplasty [38]. Of note, cine-MR has been proposed to aid in the intraoperative decision to perform duraplasty during posterior cranial fossa decompression [39].

In the case of the coexistence of Arnold-Chiari syndrome with syringomyelia, subcutaneous resection of ectopic cerebellar tonsils is practiced if they are large enough to prevent adequate decompression [14]. After a successful operation, the cerebellospinal cistern is reconstructed without craniectomy and the flow of cerebrospinal fluid through the foramen magnum is restored [14, 40].

It is worth emphasizing that syringomyelia, which is the result of pressure within the occipital foramen, in most cases undergoes spontaneous, spontaneous limitation after decompression, therefore direct surgical intervention within the fissure in the spinal cord is not necessary. Its opening and drainage are performed in extremely rare cases when syringomyelia progresses radiologically or clinically despite properly performed decompression of the foramen magnum [14].

Among some patients, normal circulation of cerebrospinal fluid cannot be restored after the procedure. There is a need to use a ventriculoperitoneal shunt, especially if the intracranial pressure is significantly increased. To avoid intussusception, in some clinics, patients with high intracranial pressure are qualified for shunt implantation before planned decompression of the posterior cranial fossa [14].

Another type of procedure that may be of benefit in a subset of patients with spinal anchoring is surgical cutting of the terminal cord, a thin band of fibrous tissue that extends between the conus medullaris and the inferior portion of the dura mater. This structure does not perform any physiological function, and in some cases it may be fixed in the spinal canal so strongly that, through traction, it causes pressure within the foramen magnum [14]. Spinal cord anchoring is a common problem among children with congenital spina bifida and Chiari malformation type 2 or terminal cord fibroma. Terminal suture cutting is a common procedure in pediatric neurosurgery, but is very rarely indicated in adult patients with type 1 Chiari malformation, except for a small subgroup with spinal anchorage [41].

Very rarely, when Arnold-Chiari syndrome type 1 is caused by instability of the atlantoaxial joint, intervention to stabilize the cervical spine may be necessary [56]. In exceptional cases, it may be supplemented with anterior decompression of the medulla oblongata using a transoral approach [43].

Among patients with typical symptoms and radiological changes, surgical results are usually good. The key stage is appropriate qualification for the procedure. Before surgery, patients should be informed about the long recovery period and possible postoperative ailments.

The most common postoperative complication is cerebrospinal fluid leakage and meningeal hernia (cyst) [44]. The latter may require revision surgery or valve implantation [45]. Other complications include persistent nausea, dizziness, bacterial or aseptic meningitis, vertebral artery injury, or epidural hematoma [46].

Post-surgery patients may experience symptoms such as headaches and neck pain. Neck muscle exercises can be helpful in restoring full mobility and speeding up the rehabilitation process. The recovery time is approximately 4-6 weeks. It is important to increase activity slowly and gradually, without suddenly lifting weights in the early phase of recovery. After 6 months, a follow-up MRI is recommended [1].

Regarding the safety of individual surgical treatments, in a retrospective analysis, Farber et al. found that meningitis occurred especially in cases of decompression and duraplasty performed using xenograft compared to allograft [47].

Summary

Arnold-Chiari malformation is often discovered incidentally. If the features observed on MRI suggest the above diagnosis, the patient should be referred to a neurologist. After excluding other possible causes of the imaged morphological features and performing a dedicated magnetic resonance imaging examination, the neurosurgeon decides whether to qualify for the procedure. In a selected group of patients, significant improvement can be expected after surgical treatment [14].

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