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Prognostic Determinants in Basilar Invagination Surgery: Current Advances

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Abstract: ***Surgery is an important means to delay the further aggravation and deterioration of neurological and mental symptoms in basilar invagination. The prognosis of basilar invagination surgery is affected by various factors, including the patient's age, disease duration, type of basilar invagination, timing of surgical intervention, and the degree of surgical reduction. Currently, there are articles that have studied each of these influencing factors, but the research results vary, and there are differences in opinions on some of the influencing factors. For patients with basilar invagination, the degree of improvement in symptoms after surgery is a concern for patients. Therefore, it is worth summarizing the prognostic factors for surgical treatment of basilar invagination.***

Keywords: Basilar invagination, Surgical treatment, Prognostic factors.

1. Introduction

Basilar invagination is a common malformation at the cranio-cervical junction. Its main manifestation is the upward displacement of the odontoid process, which compresses the medulla oblongata and causes a series of neurological symptoms, including headache, limb numbness, and paralysis [1]. The prognosis assessment of this disease is a complex process involving multiple clinical factors and imaging indicators [2,3]. This article reviews the methods of prognosis assessment, clinical predictive factors, and the influence of imaging evaluation indicators for basilar invagination, aiming to provide clinicians with a comprehensive framework for predicting and managing the long-term outcomes of this disease. Regarding the surgical indications for basilar invagination, most scholars currently believe that surgical intervention should be performed when patients have severe symptoms or progressive neurological deficits to relieve symptoms and prevent further deterioration [4]. However, in clinical practice, due to the irreversible nature of nerve damage, the effect of surgical intervention may be poor when patients present with severe clinical symptoms or progressive neurological deficits. Therefore, a thorough preoperative assessment of the patient's prognosis and selection of the appropriate time for surgical intervention are crucial for achieving a relatively favorable outcome. Currently, some scholars have conducted studies on the prognostic factors of basilar invagination. The main factors affecting the prognosis of basilar invagination are currently believed to include patient age, disease duration, symptoms, and imaging indicators: the distance of the odontoid process above the Chamberlain line, the clivus-axial angle, ADI, SSA, and Boogard angle. The following will introduce these articles one by one.

2. Age and Disease Duration

The occurrence of related neuropsychiatric symptoms in BI gradually increases with age. Some scholars believe that the prognosis of patients with basilar invagination gradually worsens with age. A study included 94 patients, with ages ranging from 29 to 49 years. Through machine learning statistics, it was found that the prognosis of patients was significantly associated with age [5]. Through analysis, it was concluded that the prognosis of patients gradually worsened with age. However, some scholars, through research, pointed out that the association between age and prognosis of patients was not strong. This study included 87 patients, with ages ranging from 18 to 80 years. When age was used as an independent risk factor and linear regression analysis was conducted, it was found that age was not significantly associated with prognosis [6].

The author believes that the prognosis of patients is related to both age and disease duration. However, compared to age, disease duration has a greater impact on prognosis. The symptoms of basilar invagination are mainly due to the upward displacement of the odontoid process, causing nerve-related damage. As the disease duration gradually increases, the time of nerve damage in patients becomes longer. Even if surgery is performed, the damaged nerves cannot be saved, resulting in some symptoms not being relieved. Older patients often have a longer disease duration, leading to postoperative symptoms not being improved compared to preoperative conditions. Younger patients have a relatively shorter disease duration, and their symptoms are more likely to improve. This does not indicate a significant association between age and prognosis. Instead, due to the irreversibility of nerve damage, the association between disease duration and basilar invagination is relatively stronger.

3. Symptoms

The symptoms of basilar invagination mainly include pain, sensory or motor disorders of the limbs, etc [7-9]. As the patient's condition gradually worsens, their symptoms will also change, such as from early sensory disorders of the limbs to motor disorders. These changes in symptoms can usually indicate the patient's prognosis. For example, when patients have severe motor disorders, postoperative motor improvement is usually poor, indicating a poor prognosis10. Some literature also points out that preoperative symptoms such as head and neck pain and sensory disorders have no significant association with prognosis8. These symptoms of pain and numbness often occur in the early stage of medullary compression, suggesting that early surgical intervention in the

early stage of the disease may have a smaller impact on prognosis. However, some scholars believe that patients with type A (more cases of dizziness) and type B (more cases of ataxia) can achieve better long-term prognosis after clinical intervention [10]. However, we cannot ignore that if intervention is not made until the symptoms of basilar invagination are severe, such as limb paralysis, surgery cannot significantly improve the prognosis, leading to a high disability rate. Currently, most scholars believe that the appropriate surgical timing is when patients have neurological dysfunction and symptoms are progressively worsening. Therefore, when patients experience changes in symptoms, surgeons need to grasp the appropriate surgical timing [11].

4. Imaging Indicators

Imaging examination is a necessary condition for diagnosing basilar invagination [12]. In addition to being diagnostic indicators, many imaging data are also used for prognosis assessment. Currently, widely recognized imaging indicators for evaluating basilar invagination include pCXA, pCS, pCMA, pBoogaard's angle, postoperative downward displacement distance, ADI, foramen magnum angle (FMA), etc [13].

Currently, there are many imaging indicators used to evaluate the prognosis of patients with basilar invagination. Widely recognized imaging indicators include:

1) CXA: Slope-axial atlas angle [14]. It is the angle between the slope and the posterior edge of the odontoid process of the atlas. It is a representative of craniovertebral junction malformations and is also used for diagnosing flat craniovertebral junction malformations [15]. Currently, it is believed that the normal CXA angle is between 130° and 145°. Less than 125°: This may indicate an abnormality in the craniocervical junction, especially related to basilar invagination, Chiari malformation, and platybasia, which may exert compression on the spinal cord and brainstem [16]. The clivus-axial angle has been statistically analyzed and found to be significantly associated with the prognosis of patients with basilar invagination. A smaller clivus-axial angle often indicates a poorer prognosis [17,18], which may be related to more severe compression of neural structures and cerebrospinal fluid dynamics disorders, often leading to irreversible neurological damage and a poorer prognosis for the patient.

2) CS angle: The angle formed between the clivus in the sagittal plane and the anterior-posterior axis of the skull base [19]. Some studies have suggested that a reduced CS angle may affect the prognosis of patients. Currently, it is believed that unless the CS angle exceeds 63.4°, it is negatively correlated with the prognosis of patients diagnosed with BI. However, the author believes that this indicator is highly influenced by the patient's head position and external factors. An indicator for evaluating patients should be quantifiable; otherwise, the results may be significantly biased.

3) Boogaard's angle: The angle formed between the anterior and posterior edges of the foramen magnum and the clivus. Patients with a poorer prognosis often have a smaller Boogaard's angle. Some studies have suggested that the prognosis of patients is closely related to Boogaard's angle, and this angle is not affected by surgical outcomes or the reduction of the odontoid process, making it a relatively objective indicator for evaluating the prognosis of patients [20].

4) Postoperative downward reduction distance: Some scholars believe that the prognosis of patients with basilar invagination is related to the distance of downward reduction of the odontoid process after surgery [21]. They suggest that the greater the downward reduction, the better the prognosis. However, for patients with significant upward dislocation of the odontoid process, excessive downward reduction may lead to severe complications.

5) CMA: The Cervicomedullary Angle [22], which is the angle formed between the ventral surfaces of the medulla oblongata and the spinal cord in the median sagittal plane. In normal individuals, the CMA is usually greater than 135°. A significantly reduced CMA often indicates severe compression of the medulla oblongata and spinal cord by basilar invagination. If the angle is restored to >135° after surgery, it is significantly associated with a good clinical prognosis [23-26].

6) Atlanto-dental interval (ADI): The distance between the line connecting the midpoints of the anterior and posterior arches of C1 and the odontoid process of C2 [27]. When the ADI is greater than 3mm, it can be diagnosed as atlantoaxial dislocation. In patients with basilar invagination accompanied by atlantoaxial dislocation, the ADI is widened. After surgical treatment and horizontal reduction, the ADI decreases, and a smaller ADI often indicates a better prognosis for the patient [28].

The author believes that when using imaging indicators to assess the prognosis of patients, preoperative indicators should be used as much as possible for prognosis assessment. This is because a good preoperative assessment of the prognosis allows patients to choose whether to undergo surgery, which is more in line with modern medical perspectives. If postoperative imaging indicators are used for assessment, it is difficult to accurately evaluate the degree of prognosis improvement before surgery and help patients choose the most suitable treatment method.

5. Scoring Criteria for Prognosis Assessment Improvement

Currently, the preoperative and postoperative prognosis assessment of basilar invagination mainly uses the Japanese Orthopaedic Association (JOA) score. In 1975, the Japanese Orthopaedic Association developed the JOA scoring system based on the main symptoms and signs of cervical spine patients. The assessment includes four items: upper and lower limb motor function, sensation, and bladder function. The scores range from 0 to 4 for upper and lower limb motor function, 0 to 6 for sensation, and 0 to 3 for bladder function, with a total score of 17 points. The calculation method for the improvement rate of cervical spinal cord function after treatment is as follows: JOA improvement rate = (postoperative score - preoperative score) / (17 - postoperative score) × 100%. An improvement rate of 100% indicates a cure,

an improvement rate greater than 60% indicates significant improvement, an improvement rate of 25% to 60% indicates improvement, and an improvement rate less than 25% indicates no improvement.

To meet the demands of modern medicine for the assessment of patients' subjective symptoms and quality of life, the JOA score has been modified and shifted towards a version that relies more on patients' self-reports - PRO-JOA. The PRO-JOA score has removed the assessment of urinary function and added evaluations of daily function and pain, reflecting the quality of patients' daily lives and providing a more individualized assessment of postoperative functional outcomes [29,30]. In recent years, many scoring systems have been developed to assess the prognosis of craniovertebral malformations, such as the AIS Spinal Cord Loss Scale, the NDI Cervical Spine Function Disability Index, and the SOS-XW Syringomyelia Outcome Scale [31-33].

Although existing assessment methods provide guidance for the prognosis of basilar invagination, there are still some challenges. Moreover, the differences in treatment methods and assessment approaches among different hospitals and regions also affect the consistency of prognosis assessment. Therefore, future research should further explore multi-dimensional assessment systems, combining clinical and imaging data, to develop more precise prognosis assessment methods. Conclusion

The prognosis of basilar invagination (BI) is influenced by multiple factors, including the disease course, clinical manifestations, the degree of neurological impairment, imaging features, and treatment methods. With the continuous development of surgical techniques, imaging technologies, and clinical assessment methods, the prognosis evaluation system has gradually shifted from a single clinical judgment to a multi-dimensional comprehensive assessment, providing doctors with more comprehensive and personalized treatment guidance and more accurate recommendations for patients' treatment options.

Firstly, the disease course is crucial for the prognosis of BI patients. Clinical studies have shown that early detection of basilar invagination and timely appropriate treatment can effectively slow down the progression of neurological damage and reduce the irreversible neurological dysfunction caused by long-term spinal cord compression. Therefore, timely and appropriate treatment measures have a significant impact on the long-term quality of life and functional recovery of patients.

The severity of neurological impairment is directly related to the prognosis of BI. When early symptoms of neurological impairment appear, timely surgery can significantly improve the quality of life of patients. For those with mild nerve compression and timely decompression surgery, the chance of functional recovery is greater. However, for patients with long-term untreated or severe spinal cord injury, neurological damage is often irreversible, with poor treatment outcomes and prognosis. However, we should not ignore patients with relatively mild neurological symptoms but with gradually worsening conditions, as timely surgery can prevent serious complications.

Imaging data play a crucial role in the prognosis assessment of BI. By detailed assessment of the degree of basilar invagination, the range of spinal cord compression, and related indicators of nerve root compression, imaging examinations can help doctors evaluate the severity of the disease and predict the prognosis of patients. For example, radiological indicators such as the basion-occiput line angle, clivus-axial angle, and medullary-spinal cord angle have been proven to be closely related to the long-term functional recovery of patients. However, we should also find more accurate preoperative indicators to assess the prognosis of patients.

In terms of treatment, surgical intervention remains the main treatment method for BI patients, especially for those with severe neurological compression symptoms. Currently, the mainstream surgical approach is posterior fixation [34], while some medical centers adopt anterior fixation [35]. However, the reproducibility of anterior fixation in other medical centers and how to avoid severe infections still need further exploration. Secondly, the timing, method, and outcome of surgery are crucial for prognosis. Early and timely surgical treatment usually significantly improves neurological function, reduces pain, and restores the quality of life of patients. However, the outcome of surgical treatment is also affected by the patient's disease course, imaging indicators, and comorbidities. Therefore, individualized treatment plans need to be adjusted according to the specific conditions of patients.

Finally, multi-factor combined assessment is considered an important development direction for future prognosis evaluation [36]. Currently, assessment methods focus on single-dimensional evaluation, such as whether the basilar invagination is stable, the degree of symptoms, and whether they are progressive. However, a comprehensive consideration of clinical symptoms, imaging results, neurological function, and individual patient factors should be made to predict the prognosis before surgery, providing patients with more accurate suggestions and then adopting corresponding treatment methods.

Prognosis improvement assessment systems such as the JOA score and AIS score can combine imaging assessment and clinical symptoms to provide quantitative basis for prognosis prediction. In addition, with the progress of biomarker and genetic research, future prognosis assessment may further incorporate molecular biology and genetic factors to provide more precise guidance for personalized treatment. In conclusion, the prognosis assessment of basilar invagination is a dynamic process involving multiple factors. Accurate prognosis assessment is crucial for improving the treatment outcome, treatment approach and quality of life of patients. With the development of technology and the improvement of the assessment system, prognosis assessment will become more refined and personalized, thereby providing better treatment and management strategies for BI patients, ultimately reflecting a patient-centered approach and improving the quality of life of patients.

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