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Advances in Skull Base Reconstruction After Transnasal Endoscopy

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Abstract

Endoscopic transnasal approach have experienced rapid development and gradual maturation in just a few decades (Kassam AB, Prevedello DM, Carrau RL, et al, 2011; Eloy J A, Vivero R J, Hoang K, et al, 2009). It has expanded from the removal of conventional pituitary tumours to the application of an endoscopic extended transsphenoidal approach for the resection of tumours in the intrasellar, suprasellar and even ventricular systems (Cappabianca P, Cavallo L M, Esposito F, et al, 2008). Larger bone and dural defects at the skull base, causing more severe postoperative complications and resulting in a multiplication of the healthcare burden (Eloy J A, Shukla P A, Choudhry O J, et al, 2013). Skull base Reconstruction after tumour removal has become a great challenge. Currently, skull base reconstruction is mainly divided into soft and rigid reconstruction, and soft reconstruction is represented by the technique of pedicled nasal septum mucosal flap (PNSF) (Thorp B D, Sreenath S B, Ebert C S, et al, 2014)[0]. As for rigid reconstruction, it is still controversial (Shin J, Forbes J, Lehner K, et al, 2019; Eloy J A, Shukla P A, Choudhry O J, et al, 2012). From the current studies, rigid reconstruction has a role that cannot be ignored. In this article, we will describe the development of skull base surgery and several high-profile skull base reconstruction techniques.

Keywords: neuroendoscope, skull base reconstruction, In Situ Bone Flap, review

1. Introduction

Compared with traditional craniotomy, endoscopic transnasal approach has significantly fewer postoperative complications, low mortality, and the absence of postoperative surgical incisions improves their postoperative experience and reduces patients' healthcare expenditures (Cappabianca P, Cavallo L M & De Divitiis E, 2004). Neuroendoscopy is gradually becoming the surgical modality of choice for the removal of lesions in the saddle region and even throughout the skull base. The ever-increasing bone and dural defects at skull base place higher demands on skull base reconstruction techniques (Komotar R J, Starke R M, Raper D M S, et al, 2012). They can be broadly classified as free tissue grafting techniques, PNSF, synthetic material techniques or a combination of various techniques (Esposito F, Dusick J R, Fatemi N, et al, 2007; Hara T, Akutsu H, Yamamoto T, et al, 2015; Kassam A B, Carrau R L, Snyderman C H, et al, 2008). All of them have different effects on the skull base reconstruction. In this article, several of these popular reconstruction techniques will be described.

2. Occurrence and Development of Transnasal Endoscopy

Technological advances have revolutionised the medical field, particularly in medical devices and surgical techniques, and have greatly contributed to the understanding and development of the discipline of skull base surgery. A milestone in 1901 was the first use of Hirschmann's modified cystoscope for urological use in the observation of sinuses, an innovative application that was successfully used in the treatment of chronic sinusitis in 1903, ushering in the use of endoscopy in surgery. This innovative application was successfully used to treat chronic sinusitis in 1903, ushering in a new era of surgery using endoscopy. Subsequently, Giordano's detailed autopsy of cadavers deepened the medical community's understanding of transnasal sinus surgery, and Schloffer's report of transnasal resection of pituitary tumours, as well as Cushing's refinement of this method, laid the foundation for the development of transnasal surgical techniques. The introduction of the microscope led to a leap forward in transnasal sinus surgery, and endoscope-assisted microsurgery followed, further advancing the field. In particular, the case of transnasal pituitary microadenoma surgery performed independently using an endoscope, reported by Jankowski et al. in 1992 (Jankowski R, Auque J, Simon C, et al, 1992), signalled the beginning of a wider acceptance and application of this surgical approach. Rapid advances in imaging technology have provided precise navigation for surgical planning and execution, allowing for more accurate judgement of surgical access and tumour relationships. The continuous innovation and improvement of surgical tools and materials have simplified the surgical process and reduced the risk of postoperative complications (Cappabianca P, Cavallo L M & De Divitiis E, 2004). The intervention of the multidisciplinary team, especially the cooperation of the endocrinology department, has optimised the postoperative patient management and shortened the recovery time. Today, skull base surgery largely eschews microscopic operations and the use of transnasal endoscopy is expanding to cover almost the entire skull base.

3. Common Techniques and Materials for Skull Base Reconstruction After Endoscopic Sinus Surgery

Following transnasal endoscopic surgery, skull base reconstruction is a crucial surgical step that aims to repair the post-surgical defects in the skull base in order to restore the structural integrity of the skull base, to prevent leakage of cerebrospinal fluid (Cappabianca P, Cavallo L M & De Divitiis E, 2004), and to provide adequate support to protect the brain and neural structures. This process involves the selection and application of multiple techniques and materials to ensure optimal surgical outcomes. Firstly, in terms of material selection, autografts and synthetic materials are commonly used. Autografts, i.e., materials taken from other parts of the patient's own body, are the most desirable choice because they are extremely biocompatible and less likely to trigger an immune response, commonly with autologous bone grafts (Leng L Z, Brown S, Anand V K, et al, 2008). However, the limited amount of tissue available and the potential for increased pain and recovery time in the surgical area make synthetic materials an important alternative option. Synthetic materials, on the other hand, include titanium mesh, porous polyethylene, collagen-hydroxyapatite, poly-ether-ether-ketone (PEEK), and bone cement (Khan A, Lapin A & Eisenman D J, 2013; Badie B, Preston J K & Hartig G K, 2000; Brandicourt P, Delanoé F, Roux F E, et al, 2017), which provide good structural support and promote bone tissue growth to some extent. In recent years, with the development of technology, 3D printing technology has also been introduced into skull base surgery (Choi J W & Ahn J S, 2014)[0], and this technology allows for the customisation of personalised implants based on the specific defects of the patient's skull base. These personalised implants not only precisely match the patient's anatomy, but also improve the accuracy of reconstruction and patient satisfaction. In addition, with the advancement of bioengineering technology, bioactive materials such as bioceramics and bioglass are being used more and more widely in skull base reconstruction, which can promote the regeneration and repair of bone tissues, thus improving the success rate of the surgery; The Gasket-seal technique is a typical combination of rigid reconstruction and soft reconstruction, which has a good watertight reconstruction effect, and plays a good role in the repair of high-flow cerebrospinal fluid leakage. The saddle-base dural suture technique is gaining popularity because it minimises the dural defect. The In Situ Bone Flap (ISBF) technique is of great interest because of its true anatomical reconstruction of the skull base.

3.1 Gasket-Seal Technology

The Gasket-seal (Leng, Lewis Z. M.D., Brown, Seth M.D., Anand, Vijay K. M.D., Schwartz, Theodore H. M.D, 2008) technique is a typical skull base reconstruction technique that combines soft and rigid reconstruction to effectively accomplish skull base reconstruction and achieve the goal of reducing cerebrospinal fluid leakage, and its steps can be divided into the following: firstly, elimination of the dead space with autologous fat prevents cerebrospinal fluid leakage (CSF) from pooling at the closure. If the third ventricle is widely open intraoperatively, this step is usually skipped to prevent graft displacement into the ventricular system and obstruction of the aqueduct. Next, a piece of autologous fascia is taken and shaped larger than the skull base defect, and the radius of the graft must exceed the bone defect by at least 1 cm. The graft is then placed in the centre of the defect. Thirdly, a piece of rigid material, such as pear bone, septum bone, titanium plate, artificial bone and other rigid materials are made into the size of the bone window and placed in the centre, ensuring that there is 1 cm of fascia around it. Fourth, a bone fragment, etc., is buried into the bone window. The fascia will be drawn into the bone window, forming a watertight gasket seal around the bone fragments etc. Check for CSF leakage. If the CSF is still leaking, either reseal or place a lumbar drain. Fifth, a sealant is dripped or sprayed around the edges and top of the construct; polymerized hydrogel (DuraSeal) is preferred, and fibrin glue is also appropriate. In addition, endoscopic 3D reconstruction of the surface anatomy of the skull base can more accurately depict the surgical defect, and the combination of the two can do a good job of reproducing the very thin bony and mucosal surfaces typical of the anatomy of this region. The technique can be better served. However, the technique is cumbersome to fabricate, requires the removal of autologous fascia (Johannes M S, Jürgen B, Stephan M, et al, 2023), and the rigid grafts do not fit tightly to the skull base and are prone to displacement with unpredictable consequences.

3.2 Saddle-Base Dural Suture Technique

This technique was initially used in microscopic surgery (Hara T, Akutsu H, Yamamoto T, Tanaka S, Takano S, Ishikawa E, Matsuda M & Matsumura A, 2015) and was initially not widely used due to the difficulty of the procedure, the test of the operator's skills, and the extra time consumed during the procedure. Later, with the rapid development of endoscopy, knot tying equipment and wider endoscopic exposure, the technique was gradually utilised. As with conventional craniotomy, although watertight suturing of the dura mater cannot be achieved (Nishioka H, Izawa H, Ikeda Y, et al, 2009; Ishii Y, Tahara S, Hattori Y, et al, 2015), the meningeal suture provides reliable tension support, relieves cerebrospinal fluid pressure, and reduces the use of spinal canal drainage (Heng L, Zhang S & Qu Y, 2020). By suturing the dura mater, the dura mater at the skull base is restored to its preoperative state, which serves to support the cranial structures and effectively reduces the incidence of cerebrospinal fluid rhinorrhea, and its efficacy even exceeds that of the PNSF. In addition, the dural suture technique combined with rigid reconstruction of the skull base restores the original structure of the base of the skull, which is a strong support against intracranial pressure and gravity. In addition, the dural suture technique can be mastered very quickly through research and practice in a small number of cases. However, intraoperative suturing requires careful discrimination of the structures in the operated area, which tests the operator's microscopic suturing technique. Therefore, this technique needs to be further developed.

3.3 In Situ Bone Flap (ISBF) Technique

The difficulty of anatomical reconstruction of the skull base has always bothered skull base surgeons, and our team innovatively proposed the ISBF (Biao J, Xiao-Shu W, Gang H, et al, 2020; Xia Hailong, Jin Biao, Mou Jiamin et al, 2020; Yu Jiaojiao, 2022) technique to complete in situ reconstruction of the skull base, which has been recognised by many skull base surgeons around the world. In the preliminary follow-up, it was not only confirmed that ISBF is safe and feasible either in combination with a PNSF or with a free middle turbinate mucosal flap (FMTMF), but also has great advantages in reducing cerebrospinal fluid leakage, shortening hospital stay, and intracranial infection incidence. In addition, the long term postoperative follow-up showed that the bone flap healed well, with no deviation in position, anatomical reconstruction of the skull base, restoration of the original hierarchical structure of the skull base, and the tendency of the bone flap to heal with the original bone window. Sealing the skull base prevents gas from entering to form a pneumocranium and also provides support to relieve the gravity of the brain, as well as protection for the nerves, vessels and functional areas of the brain. Additionally, ISBF eliminates the need to use tissues such as broad fascia for tamponade of the operative area, which reduces patient trauma and improves the patient's postoperative experience. The In Situ Bone Flap technique has also been continuously developed and improved. Since PNSF requires reversing the mucosal flap of the nasal septum, which is highly traumatic to the patient's nose, PNSF has gradually been replaced by FMTMF, which was originally cut intraoperatively to expand the field of view. This technique achieves the best use of its resources, maximising the patient's surgical outcome and improving the post-operative experience. It achieves true minimally invasive and anatomical reconstruction of the skull base. However, the ISBF technique is not suitable for patients whose preoperative three-dimensional reconstruction of the saddle region shows poor pneumatisation of the pterygoid sinus and bone defects at the skull base.

4. Summary and Prospect

With the continuous updating of navigation and endoscopic equipment and the maturation of image post-processing technology, transnasal endoscopy can be said to be developing rapidly. Its application range is expanding, and the size of the lesions handled is gradually becoming larger and the anatomical location of the lesions more complex. Correspondingly, the defects of the skull base are also expanding, which puts higher demands on the techniques of skull base reconstruction. Currently, there are a number of effective solutions for rigid reconstruction and soft reconstruction of the skull base. There is no unanimity yet, and the ideal would be to achieve anatomical reconstruction. But with the understanding of the anatomy of the skull base, the development of assistive devices, and the advancement of surgical techniques, we are getting closer to this goal, so that more patients will be benefited.

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