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Research Progress of Artificial Cervical Disc Replacement

Junbin Zhu

The first Clinical College, Jinan University, Guangzhou 510632, China

Abstract

At present, the incidence of cervical spondylosis shows an increasing trend year by year in our country. Anterior cervical decompression and fusion surgery (ACDF) has been widely accepted for its simple operation and satisfactory treatment result. However, over time, many patients developed adjacent segment degeneration during long-term follow-up. Surgical segmental fusion can cause the loss of cervical motion, which leads to the occurrence of adjacent vertebra disease. With the continuous development and innovation of biomaterials and surgical techniques, artificial cervical disc replacement (ACDR) has emerged, which not only has satisfactory clinical efficacy, but also can reduce the risk of neighboring vertebral disease. In recent years, remarkable progress has been made in the treatment of cervical disc degenerative diseases. The research progress of ACDR was reviewed, including the design optimization of artificial cervical disc, the selection of surgical indications, and the study of postoperative complications. Advances in ACDR research continue to promote the development of the field of cervical spine disease treatment. With the continuous innovation of science and technology and the continuous progress of surgical technology, ACDR surgery is expected to achieve more accurate, safe and effective treatment in the future, benefiting more patients.

Keywords

Artificial cervical disc; Artificial cervical disc replacement; ACDF; Research progress.

1. Introduction

Cervical spondylosis refers to degenerative changes in the discs, vertebrae, joints, and surrounding soft tissues in the cervical region, resulting in reduced disc height, bone hyperplasia, and possibly intervertebral arthritis. These changes can lead to compression of nerve roots, causing neck pain, shoulder pain, upper limb radiation pain, numbness and other clinical symptoms. Cervical spondylosis is a disease that develops gradually with age and is usually more common in middle age and the elderly. Studies have shown that the incidence of cervical spondylosis is gradually increasing and trending younger, which may be related to factors such as improving living standards, increasing work pressure, sedentary lifestyles, and the increasing use of electronic devices. Long-term poor working posture, lack of exercise, and lack of good cervical health practices are also possible contributing factors [1]. Singh et al. [2] made a statistical analysis of 200 patients with cervical spondylosis and concluded that the changes in vertebral canal ratio, vertebral canal diameter, cervical vertebral diameter, race, weight and height of patients were not risk factors for cervical spondylosis. Age, sex and occupation were the only risk factors for cervical spondylosis.

The clinical symptoms caused by cervical spondylosis often have a certain impact on the quality of life of patients. For patients who have failed conservative treatment and need surgical treatment to reduce the symptoms, artificial cervical disc replacement is an important operation for the treatment of cervical degenerative changes in recent years. Different from the traditional decompression fusion surgery, it not only solves the problem of cervical spondylosis in patients, but also preserves the motion of the cervical spine, reduces the stress of the

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neighboring vertebra, and thus reduces the occurrence of adjacent vertebral diseases, becoming a milestone in the surgical treatment of cervical spondylosis.

2. Development and research status of artificial cervical intervertebral disc

2.1. Appearance and development of artificial cervical disc

In 1956, Van steenbrugghe first proposed the concept of artificial disc [3]. In the 1960s, Fernstrom performed the first cervical disc replacement using a steel ball bearing design, and more than 250 patients have since undergone the procedure. However, the operation ended in failure, and many patients had poor prognosis and some prosthesis related complications appeared. For example, some patients had excessive displacement of the replacement segment after surgery, and the prosthesis broke through the endplate, resulting in stenosis of the vertebral space [4]. The Bristol prosthesis, an early product of Prestige's disc, was introduced in the 1980s when Bristol, at Frenchay Hospital's Department of Medical Engineering, began designing a new artificial cervical disc. The prosthesis is composed of a restrictive metal-on-metal design with stainless steel components on both sides. The upper and lower endplates can be fixed to the vertebral body by screws. The ProDisc disc appeared at the same time and was an upper and lower end plate made of cobalt-chromium-molybdenum (CoCrMo) material with a pure titanium coating. The intermediate insert is made of ultra-high molecular weight polyethylene. In the 1990s, the Bryan Disc was introduced, and it was the first product with an artificial joint capsule design. Its nucleus pulposus is made of polyurethane, which gives it a certain elasticity and flexibility. The two sides of the Bryan are titanium alloy endplates, and the outer surface of the endplate is formed by surface modification to promote bone integration. Since the 21st century, the emergence and application of Bryan, Prestige LP, Pro DisC-C, PCM and Mobi-C have promoted the development of artificial cervical Disc. Although the development process has experienced twists and turns and challenges, its continuous progress has never stopped.

2.2. Types of artificial cervical discs

There are currently seven artificial cervical discs that have been approved by the Food and Drug Administration for marketing: Prestige LP Discs (Medtronic, USA), Prestige ST Discs (Medtronic, USA). USA), Prodisc-C discs (Johnson and Johnson, USA), Bryan Discs (Medtronic, USA), Secure-C (Globus Medical, USA), PCM discs (Medtronic, USA) USA), Mobi-C (Zimmer Biomet, USA) [5].

Prestige Disc: The Prestige artificial cervical disc is an artificial cervical disc developed by Brian Cummins since 1989 in collaboration with the Department of Medical Engineering at Frenchay Hospital in Bristol, UK, to address the shortcomings of cervical arthrodesis. Their efforts to develop metal-to-metal artificial cervical discs laid the foundation for the Prestige artificial cervical disc system. The disc consists of a metal-to-metal ball-and-socket structure with movable joints. The upper and lower ends of the anterior disc can be fixed to the vertebral body with screws. Because the articular surface is metal-to-metal structure, the metal debris generated during the long time of activity leads to the dislocation and subsidence of the prosthesis. Cummins subsequently improved on the Prestige disc with the Prestige II and Prestige ST discs. The Prestige II replaced the hemispherical concave with an ellipsoidal groove, making it more in line with normal physiological activity. The surface modification also increases the roughness of the surface of the upper and lower endplate materials, which is more conducive to the growth and insertion of bone trabeculae, thereby improving the stability of the connection between the intervertebral disc and the surrounding bone, and ultimately achieving long-term stability. Prestige LP disc as the latest Prestige series disc, it has the characteristics of wear resistance, mechanical properties and biocompatibility, the end plate

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material surface using a special ceramic surface modification technology for titanium alloy modification, resulting in the long-term stability of Prestige LP disc after ACDR. It has good benefit in clinical application. Zeng et al. [6] believe that Prestige LP cervical disc replacement is an effective surgical method for the treatment of cervical degenerative disc lesions. They had satisfactory clinical results for at least 6 years of follow-up after Prestige LP disc replacement, with most prostheses maintaining good range of motion, good range of motion (ROM) in adjacent segments, and only 6.6% of symptomatic ASD. Although the incidence of HO was 42.9%, none of them showed clinical symptoms.

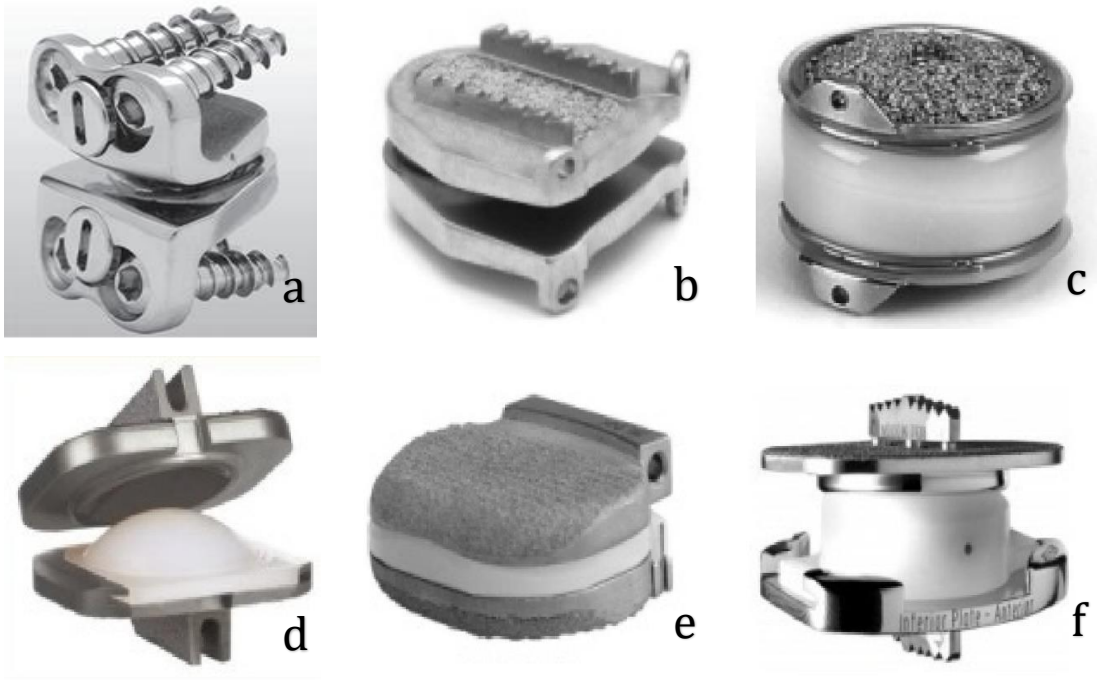

Figure 1 Several common artificial cervical disc products (a) Prestige ST disc (b) Prestige LP disc (c) Bryan disc (d) Prodisc-C disc (e) PCM disc (f) Mobi-C disc

Bryan Disc: The Bryan disc is a bionic artificial cervical disc designed by neurosurgeon Vincent Bryan that simulates the structure of a natural cervical disc, thereby restoring cervical motion and stability. It consists of a polyamine inner core similar to the annulus fibrosus and nucleus pulposus, as well as an outer sheath, which provide elasticity and flexibility similar to that of a natural disc. In addition, Bryan has titanium end plates on both sides of the disc, providing additional stability and support. At the same time, the outer surface of Bryan's disc endplate was modified to form a microporous structure. These micropores help promote the growth and insertion of the surrounding bone tissue, thereby promoting the fusion and stabilization of the disc with the surrounding bone tissue, improving the success rate of surgery and reducing the risk of subsequent complications. But Bryan's disc replacement surgery comes with certain risks and complications. Lei et al. [7] reported that 14 out of 49 patients (28.6%) after Bryan disc replacement developed ASD, but no radiculopathy or myelopathy recurred as a result of ASD. In addition, imaging findings of prosthesis displacement >2 mm forward were found in 3 patients, and no vascular or nervous system-related complications were found. The patient reported by Parkinson and Sekhon [8] developed HO 17 months after Bryan's cervical disc joint replacement. Fong et al. [9] reported that kyphosis occurred in 9 out of 10 postoperative patients during 3-12 months of follow-up.

Prodisc-C disc: The Prodisc-C disc is constructed of metal and UHMWPE, and the ball-and-socket joint design is similar to the Prestige LP disc. However, unlike Prestige LP, the joint

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structure is formed by a ball-and-socket concave surface above and a UHMWPE spherical convex surface below, allowing it to mimic the movement of normal cervical vertebrae. The end plate of the Prodisc-C disc is made of cobalt-chromium alloy, the metal surface is sprayed with titanium ions, and the position is fixed by two wing-like structures. The series also includes ProDISC-C Nova and Prodisc C Vivo. However, some studies have pointed out that the operative segment motion decreased after Prodisc-C replacement [10].

PCM disc: The end plate of the PCM disc is made of cobalt-chromium alloy, and the core is UHMWPE. The surface of the PCM disc is covered with a porous hydroxyapatite coating, which is conducive to the growth of the surrounding bone tissue, and enhances the adhesion and stability of the artificial disc and the surrounding bone tissue. It has a certain degree of mobility, simulates the movement of natural cervical vertebrae, and reduces the extra load on adjacent vertebrae.

Mobi-C disc: The end plate of the Mobi-C disc is made of cobalt-chromium-molybdenum alloy, with an inner layer of pure titanium and an outer layer of hydroxyapatite coating on the outer surface, and the middle lining material is UHMWPE, titanium and hydroxyapatite coating surface modification, which facilitates bone growth. The upper and lower plates of the implant have transverse serrated structure, which improves the stability of the implant after insertion. At present, Mobi-C prosthesis is mainly used in European countries, with few domestic applications.

2.3. Components of artificial cervical disc

The material selection of the artificial cervical disc should not only meet the maximum motion load of cervical motion, but also withstand the continuous load generated by the daily activities of the cervical spine. Bennett et al. [11] reported a study related to cervical spine movement, which analyzed the characteristics of cervical spine activities in daily life and showed that the number of cervical spine movements was about 100,000-40,000 times/year. Considering the selection of material characteristics such as material strength, corrosion resistance, biocompatibility, wear resistance and elastic modulus for the production of artificial cervical disc materials, the materials currently on the market for the design of artificial cervical disc include metals, ceramics and polymers. Medical ceramics have good wear resistance, but they are prone to fracture. UHMWPE has many excellent properties, it exhibits a high modulus in bending and stretching, etc., giving it an advantage in areas where rigidity and strength are required. Second, UHMWPE exhibits excellent wear resistance against wear and wear caused by friction. Chemical stability It has good chemical stability and high resistance to most acids, bases and solvents, making it widely used in various fields. The current types of implantable metal biomaterials are titanium and its alloys, stainless steel and cobalt-chromium alloys. Among these materials, titanium and its alloys are valued for their higher biocompatibility, mechanical properties, excellent corrosion resistance, high strength and relatively low weight compared to other alloys [12,13]. Titanium alloys exist in α phase, near α phase, α+β phase, metastable β and stable β. The incorporation of alloying elements can be used as stabilizers for α phases (i.e. O, Hf, Ta, N, Al, and C) or β phases (i.e. H, Nb, V, Si, Co, Fe, Mo, Mn, Mo, and Ni) or neutral elements (i.e. Zr) [14]. α-phase and near-α-phase titanium alloys have high corrosion resistance, but their mechanical properties are limited. On the other hand, compared with α alloys, β-phase titanium alloys have poor corrosion resistance, but can be molded at relatively low temperatures due to their body-centered cubic crystal structure. Therefore, combining the advantages of the alpha and beta phases can produce titanium alloys that are very suitable for orthopedic implants [15,16]. The most common grade of biomedical titanium alloys used for bone replacement is grade 5, called Ti6Al4V, with components of 6% Al and 4% V. The addition of these elements can significantly improve the mechanical strength of titanium alloys as they can act as stabilizers for the alpha + beta phase of titanium [17]. Clinical studies have shown

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that vanadium ion and aluminum ion will be precipitated from Ti6Al4V alloy. However, vanadium ion and aluminum ion are not biocompatible and have certain toxicity. Their adverse effect is to reduce the adaptability of human cells, which may cause harm to human body [18], which also becomes the driving force for developing a new generation of biomedical titanium alloys. Therefore, the protective layer or biomodified layer formed after modification on the surface of titanium alloy can significantly improve the long-term stability of titanium alloy in vivo and reduce the toxicity to human cells.

2.4. Material surface modification of artificial cervical disc

Titanium alloys may release vanadium and aluminum ions when implanted in the body, resulting in inflammation of the surrounding tissues, which affects the adaptability of human cells and may lead to problems with loosening or sinking of the prosthesis. Untreated titanium implants consistently have a bioinert surface that slows bone fusion in vivo. In order to enhance their biological properties, it is a common method to modify the surface of medical metal materials. Surface modification is to improve the biocompatibility of materials by changing the surface composition, structure, morphology, hydrophilicity and other factors. Surface modification methods can be roughly divided into the following three categories: physical surface modification, chemical surface modification and biological surface modification. Physical surface modification is to treat the surface of the material by mechanical or physical means, such as frosting, sandblasting, polishing, etc., to change the morphology and structure of the surface, so as to improve its biological properties. Chemical surface modification is the formation of a specific chemical structure or chemical composition on the surface of a material by chemical means to improve its biocompatibility. Common chemical surface modification methods include surface solution treatment, chemical bonding, electrochemical treatment, etc. Biological surface modification is the introduction of bioactive molecules or biorelated structures on the surface of materials, such as proteins, peptides, extracellular matrix components, etc., in order to simulate the microenvironment of biological tissues and improve the biocompatibility and bioactivity of materials. These surface modification methods significantly improve the biological properties of the material without affecting its intrinsic properties, thereby reducing the inflammatory response of the surrounding tissue and reducing the risk of loosening or sinking of the prosthesis. Gulati et al. [19] prepared Ti-6Al-4V alloy implant using 3D printing technology, and obtained a hierarchical structure composed of micron-scale spherical particles and titanium dioxide nanotubes on its surface through anodic oxidation technology, which can enhance the adhesion and biocompatibility of bone cells.

2.5. Physical surface modification

Physical surface modification refers to changing the morphology, structure or properties of the surface by mechanical or physical means rather than chemical reaction in the process of material surface modification. These methods usually do not change the chemical composition of the material, but instead form a modification layer on the surface, which enables the desired performance improvement.

Thermal spraying modification: Thermal spraying is an effective technology for improving wear resistance and biocompatibility by applying coatings. Thickness ranges from a few microns to millimeters. The main methods of thermal spraying include high-speed oxygen fuel spraying, flame spraying, plasma spraying and so on. These methods can provide wear and corrosion resistance and are beneficial for biomedical applications [20]. The material is heated or melted during the plasma spraying process to coat the alloy surface at high speed [21]. Liu and Ding [22] used plasma spraying wollastonite coating to increase the biological activity of Ti alloy. Zhou et al. [23] also used plasma spraying to synthesize Ti alloys with thermal barrier coatings that can withstand very high temperatures. Sathish [24] proposed a novel predictor of tribological properties of plasma nitrided 316L stainless steel, which is a major achievement in

the influence of physical surface modification on the properties of stainless steel. Singh et al. [25] used atmospheric plasma spraying to obtain a functional gradient coating in Ti-Al-V alloy, which can promote the early binding of the implant with the host bone. Pillai et al. [26] prepared β-tricalcium phosphate and HA/β-TCP composite coatings by plasma spraying process, which can adjust its solubility to meet specific biomedical needs. Bai et al. [27] used suspended plasma spraying technology to prepare fluorinated hydroxyapatite coating on Ti substrate and confirmed that it has good antibacterial performance and biocompatibility. FHA coating can effectively enhance the corrosion resistance of Ti alloy, and its excellent biological characteristics have good prospects for application in orthopedic plant materials.

Physical vapor deposition modification: Physical vapor deposition modification is a common surface modification method used to form a film or coating with specific properties and functions on the surface of a material. The method involves exposing the surface of the material to the gas phase, transforming the material atoms or molecules from gaseous to solid through a physical process, depositing them onto the surface of the material to form the desired functional film or coating. Physical vapor deposition modification not only has the characteristics of high density of surface modification layer and strong binding force, but also has many choices of materials, the main processes at present include evaporation coating, ion coating and sputtering coating. Evaporative coating evaporates solid material through high temperature, and then condenses on the surface of the object to be treated to form a film. By placing the object in a vacuum chamber, a high voltage is applied to the surface of the object, causing the atoms or molecules to dissociate and ionize from the solid source material. These ions are accelerated and deposited on the surface of the object, forming a thin film. The ionic coating can improve the hardness, wear resistance, corrosion resistance and other properties of the surface of the object. This technology is often used to produce coatings with specific functions, such as anti-corrosion coatings, hard coatings, decorative coatings, etc. The sputtering coating is applied at a high voltage to the target surface, causing the atoms or molecules on the target surface to be dissociated and form ions. These ions are accelerated and hit the substrate surface, thus forming a film on the substrate surface. Diez-Escudero et al. [28] modified by physical vapor deposition to deposit silver coating with a thickness of (4.5±1.5)μm on the surface of porous Ti6Al4V alloy, which reduced the adhesion of Staphylococcus aureus on porous samples, and not only inhibited the formation of staphylococcus biofilm on the surface of the material within 72 h. After 28 days of testing, the maximum cumulative release of silver ions was lower than 3.5×10-6, and there was no toxic effect on the adhesion, proliferation and differentiation of osteoblasts. Ti-6Al-4V alloy showed good compatibility and antibacterial effect after silver plating.

2.5.1. Chemical surface modification

Chemical surface modification refers to introducing new chemical groups or changing the surface chemical composition on the surface of a material through chemical reactions, so as to improve the performance, function or application of the material. This method usually involves specific chemical treatment steps to achieve the desired surface property regulation.

Sol-gel modification: sol-gel modification is to dissolve the required chemical substances in the appropriate solvent, by controlling the pH value of the sol or temperature and other conditions, so that the sol gelation reaction occurs, forming a gel. Then the material to be treated is impregnated in the gel to coat the sol on the surface of the substrate material, and then after drying, sintering, etc., so that the composition of the sol forms a uniform film or coating on the surface of the substrate material, and finally the sol-gel modified material is subjected to appropriate heat treatment to promote the crystallization and solidification of the film or coating, thereby enhancing the performance of the material. The characteristics of sol-gel modification are that the structure and properties of the surface coating can be controlled. Since the 1970s, the sol-gel method has been rapidly developed and used in various fields of material

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engineering. Ulrich[29] in 1988 and Hench[30] in 1990 described the prospect of sol-gel modified surface modification, and its potential has been rising. Sol-gel modification as a well-known wet chemical method, not only the surface coating structure and performance is controllable, the production process is simple, and has a good potential for large-scale manufacturing, the most important is the low cost of its production method, these excellent characteristics make this production process in various fields have an irreplaceable role.

Chemical vapor deposition modification: By performing a chemical reaction on the surface of the material, a chemical substance is generated in the gas phase and then deposited on the surface of the material to form a film or coating. In the process of chemical vapor deposition, it is usually necessary to provide appropriate reaction gas and activation energy (such as heat energy, light energy, plasma, etc.) to promote the reaction and the formation of the sediment layer. Chemical vapor deposition (CVD) can control the composition, structure and properties of thin films precisely. Compared with physical vapor deposition, chemical vapor deposition has better coverage. Strokowska et al. [31] prepared diamond-based film and hydroxyapatite coating by microwave plasma assisted chemical vapor deposition and electrochemical assisted deposition, respectively. Thin diamond and hydroxyapatite surface coating were deposited on alloy Ti-6Al-4V, which is widely used in implants in contact with bone, to improve the adhesion of cells. Therefore, in order to improve the mechanical and biological properties of titanium alloys, chemical vapor deposition (CVD) modification is often used as the surface modification of these metals.

Anodizing modification: a surface treatment method that improves the performance and surface characteristics of a metal by forming an oxide film on its surface. This process involves using the metal as an anode, soaking it in an electrolyte, usually an acidic or alkaline solution, and then applying a current and voltage through the way of electricity, the surface of the metal to be treated through oxidation reaction to form a dense oxide film. The surface modification layer obtained by this method has a very high binding degree with metal materials, and the thickness parameters are controllable [32]. The metal surface oxide layer can not only improve its corrosion resistance, but also improve its biocompatibility. Among anodic oxidation techniques, microarc oxidation (MAO) can form a porous coating on the implant surface relatively efficiently. Zhou et al. [33] found that the surface of titanium prepared by MAO has a porous structure, which helps to promote the adhesion and osteogenic differentiation of bone marrow mesenchymal stem cells. They prepared porous structures with different pore sizes (3 ~ 10 nm) by adjusting the oxidation time. The results showed that the larger the aperture, the more favorable the adhesion and osteogenic differentiation of bone marrow mesenchymal stem cells. Fang et al. [34] successfully prepared TiO2 nanotube array coating with ordered structure on the surface of titanium by anodic oxidation method. Nano-silver composite titania nanotube array coating was prepared by immersion and photochemical reduction method after modified by polydopamine. The nanotube structure is helpful for loading and slow release of Ag+. Then, it was also confirmed that the composite coating has good antibacterial properties and cell compatibility through in vitro cell experiments.

2.5.2. Biological surface modification

Biological surface modification has a wide range of applications in biomedicine, biosensing, tissue engineering and other fields, which can improve the performance and function of biological materials and enhance the bionic properties of biological materials. It uses biomolecules such as proteins, peptides, nucleic acids, etc. to interact with the surface of biological materials to achieve surface functionalization. Biological modifications are often used to enhance the biocompatibility, bioactivity and biometrics of biological materials. The biological surface modification of medical metal materials not only aims to improve the biocompatibility of metal surface, but also may make metal surface have the ability to induce cell differentiation. This method of improving material properties by introducing bioactive

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substances is called biological surface modification [35]. At present, titanium dioxide silanization modification, self-assembled monolayer modification and protein fixation modification are often used to modify the biological surface of medical metal materials. The biological surface modification of metal materials can not only promote the adhesion of osteoblasts around the implant, but also load bioactive factors and make it slow release in vivo for a long time.

Titanium dioxide silanization modification: Silanization has been shown to be an effective and economical strategy for the formation of bioactive coatings [36]. Titanium dioxide silanization is achieved by introducing an organosilanizing agent on the surface of titanium dioxide. Silanizing agent molecules contain silicon-hydrogen bonds or silicon-oxygen bonds, which can chemically bond with hydroxyl groups on the surface of titanium dioxide to form stable chemical bond connections, thereby improving the surface corrosion resistance and durability of the material. Many titanium metals and titanium alloys have a titanium oxide layer, which acts as a barrier between the bioactive factor and the metal surface, preventing the combination of the two. Using organosilane covalent bond to bond TiO2, the metal surface to organosilane is helpful to improve the binding rate of titanium metal and organic matter. At the same time, this method can also convert TiO2 from a semiconductor to a conductor, which is conducive to the anchoring of enzymes on the metal surface. Based on this property, medical metal surfaces can be attached to biologically active substances, and the biocompatibility of their surfaces can be adjusted as needed [37].

Self-assembled monolayer modification: Self-assembled monolayer modification has the advantages of simple operation, low cost, and strong applicability to different types of materials. Self-assembled monomolecular membranes (SAMs) provide a simple and precise method to modify the surface of pre-activated Ti and its alloys. SAMs act as a stable and well biocompatible intermediate structure, allowing control of chemical functionality at the interface, even in complex geometry. This is important not only for controlling the interactions between surfaces, proteins, bacteria and cells, but also as a stable engineering platform to add coatings with advanced and special properties. Self-assembled monolayers are often employed because of their versatility, resulting in self-assembled monolayers by adsorbing the ordered assembly of molecular components on the surface of many materials, resulting in spontaneous thin layers [38,39]. SAMs can select and control the biological properties of titanium or other metal surfaces according to demand, so as to modify and modify the metal surface.

Protein fixation modification: By firmly attaching or adsorbing proteins to the surface of the material, thereby improving the biological activity of the material. Puleo et al. [40] aminated the surface of titanium alloy by plasma polymerization of allyl amine, then formed carboxyl group on the surface of titanium alloy by succinanhydride reaction, and then fixed bone morphogenetic protein on the surface of titanium alloy with a large number of amino groups by using carbondiamine, thus greatly increasing the amount of protein adsorption and fixation. Cai et al. [41] proved that RGD peptide is an effective peptide sequence to improve the adhesion between cells and biological materials. The modification of PLA membrane with fibroin protein can significantly promote the adhesion, proliferation and alkaline phosphatase activity of osteoblasts, and significantly improve the interface interaction between PLA and osteoblasts, thus improving the biological activity.

3. Research progress of artificial cervical disc replacement

Born in 1958, ACDF has gradually become a classic operation for the treatment of cervical degenerative disc disease by adequately decompressing spinal nerves and effectively alleviating clinical symptoms and improving nerve function, while restoring local mechanical stability through intervertebral bone grafting [42]. However, while the stability of cervical

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fusion is improved, the normal range of motion of the cervical spine is restricted, resulting in changes in adjacent horizontal kinematics. Compensatory increases in biomechanical stress and range of motion in the surrounding spinal segments are thought to accelerate their degradation and contribute to the occurrence of adjacent segment disease (ASD), with an incidence of 2.9% [43].

ACDR is a recent alternative to ACDF for symptomatic cervical spondylosis. First mentioned in the 1960s, artificial disc replacement after nerve or spinal cord decompression can preserve cervical motion, minimize biomechanical stress at adjacent levels, and reduce the risk of subsequent adjacent segment disease and re-surgery.

ACDR has some potential advantages over ACDF surgery. Preserve cervical mobility: ACDR is designed to preserve the normal physiological movement of the cervical spine. In contrast, ACDF surgery immobilizes the vertebrae, potentially causing the adjacent vertebrae to shoulder more of the burden of movement. By preserving the mobility of the cervical spine, ACDR helps maintain the natural physiological movement of the cervical spine and reduces the limitations of surgery on the intervertebral joints. Reduced stress on the adjacent vertebrae: ACDF surgery may cause additional stress on the adjacent vertebrae, potentially leading to degenerative changes in other parts of the cervical spine. The ACDR is designed to reduce this additional stress, helping to slow the development of degenerative changes elsewhere in the cervical spine. Reduced movement in the intervertebral space: ACDF surgery usually results in a loss of normal movement in the intervertebral space between adjacent vertebrae. By mimicking the movement of natural discs, ACDR helps maintain moderate movement between adjacent vertebrae and reduces stress in other parts of the cervical spine. Reduced risk of degenerative changes in adjacent segments: Some studies suggest that ACDR may reduce the risk of degenerative changes in adjacent vertebral bodies relative to ACDF. A meta-analysis of randomized controlled trials by Donnally et al. evaluated the incidence of radiographic adjacent segment degeneration and symptomatic adjacent segment disease, as well as the rate of resurgery due to adjacent segment lesions, in patients who had received ACDF versus ACDR. The analysis included a total of 18 studies involving 4,082 patients and showed that ACDR had lower rates of adjacent segment degeneration, disease, and reoperation compared to ACDF [44,45]. This is because the surgical principle of ACDR mimics natural disc function and reduces the maladaptive stress in other parts of the cervical spine.

3.1. Complications of artificial cervical disc replacement

3.2. Adjacent segment degeneration

ASD is the degeneration of a disc, spinal joint damage or bone hyperplasia, resulting in reduced stability or impaired function of this segment, which puts more burden on the adjacent disc or spinal structure, leading to its degenerative changes. Degenerative changes in adjacent segments after surgical treatment are a common complication of cervical spine surgery, but often do not present with neurological symptoms, and patients who do present with neurological symptoms often need to be treated with a second surgery. The advantages of cervical disc replacement (CDA) in the treatment of degenerative cervical spondylosis compared with ACDF surgery are that it can reduce the pressure of the adjacent disc and preserve the range of motion of the operative vertebral segment, thus reducing the incidence of ASD. Dong et al. [46] included 29 randomized controlled trials that met the inclusion criteria and conducted a comprehensive meta-analysis. Compared with ACDF, the adjacency reoperation rate in the CDA group was significantly reduced ($p<0.1$), and with the increase of follow-up time in subgroup analysis, the advantage in reducing adjacency reoperation in the CDA group increased. There was no statistically significant difference in adjacent segment degeneration between CDA and ACD during 24 months of follow-up. However, with increasing follow-up time, the incidence of adjacent segment degeneration in CDA was significantly lower

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than in ACDF ($p<0.1$). There was no significant difference in the disease of adjacent segments between CDA and ACDF ($p>0.5$). The adjacent segment ROM provided by cervical disc replacement was lower than ACDF, but the difference was not statistically significant. Nunley et al. [47] examined outcomes at 4 and 7 years for patients enrolled in five different cervical joint replacement trials and found that the incidence of symptomatic adjacent segment disease was 2.3%.

3.2.1. Reaction of wear particles and debris

Like other artificial joints, artificial cervical discs may suffer from internal structural wear during prolonged use, which is directly related to their service life. Tiny particles from internal wear can be released into the bloodstream or local tissues, triggering an inflammatory response and leading to a range of potential complications, including problems with local pain, osteolysis, artificial joint loosening and sinking. This highlights the importance of artificial cervical disc longevity and wear management. Small movements between the implant and the surrounding bone can lead to damage and absorption of the surrounding bone. In addition, friction caused by fretting between the implant and bone may produce wear particles, which may further stimulate macrophages and osteoclasts, etc., leading to inflammation and bone reaction around the implant, thus causing bone loss [48]. Roschke et al. [49] reported a case of infectious mixed inflammation and extensive osteolysis due to wear after two cervical disc replacement implants. Therefore, the study of micro-motion and wear particles between the implant and bone has become crucial, the selection of wear-resistant, corrosion-resistant high-quality materials, the use of high hardness, low friction surface coating, through the precise manufacturing and assembly process, can ensure the smooth surface of the implant, reduce the possibility of particle production, in order to reduce the inflammatory response and bone loss caused by the implant.

3.2.2. Subsidence and dislocation

Subsidence refers to the sinking of the intervertebral prosthesis to the lower vertebral endplate. Subsidence not only results in decreased motion of the operative segment, but may also lead to the occurrence of ASD. Clinical reports on the incidence of prosthesis subsidence after ACDR vary greatly, ranging from 0% to 33% [50]. The sinking of the prosthesis may be related to the following aspects: 1) The size of the prosthesis does not fit the vertebra: If the size of the prosthesis chosen is inappropriate, it does not match the size of the vertebra, which may lead to instability or sinking of the prosthesis. 2) Improper end plate treatment: If the end plate of the vertebral body is not properly treated, it may cause the vertebral body to be unable to support the prosthesis effectively, resulting in subsidence. 3) Patients with osteoporosis: Patients with osteoporosis have low bone density, which may cause the implant to be unstable and easy to sink [51].

3.2.3. Ectopic ossification

Heterotopic ossification (HO) is the abnormal ossification of soft tissues such as ligaments, muscles or discs in the spine. Ho is a common complication after ACDR. With the aggravation of ectopic ossification, the corresponding vertebral space bone fusion of the prosthesis may even occur, resulting in the loss of the function of the prosthesis. Kong et al. [52] mentioned in a meta-analysis that the incidence of ectopic ossification after ACDR was 46.4%, among which the incidence of severe ectopic ossification was 17.0%. The mechanism of ectopic ossification is not yet clear. At present, the risk factors considered for HO phenomenon may be related to age, osteophytic hyperplasia, residual bone fragments, type of surgical prosthesis, intraoperative stretch of cervical longus muscle, placement of prosthesis, and segment of replacement operation [53]. In 2003, McAfee et al. [54] first proposed the classification of HO after total disc replacement, and the severity of HO was divided into 5 levels. Grade 0, no osteophytes were found after surgery. Grade 1, the osteophyte at the postoperative operative

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level is outside the vertebral space. In grade 2, the osteophytes at the postoperative surgical level are in the vertebral space but do not bridge, and have no effect on the ROM of this segment. Grade 3, the osteophyte of the postoperative surgical segment is in the vertebral space and affects the ROM of that segment. At grade 4, the operative segment osteophyte was located in the vertebral space and formed a bridging bone. The segment was completely tetanic and the ROM further decreased. In 2006, Mehren et al. [55] improved and proposed HO classification after cervical artificial disc replacement on the basis of McAfee classification. The Mehren classification is similar to the McAfee classification, but its classification level 1 emphasizes osteophytes that occur on the anterior margin of the vertebral body, while the McAfee classification level 1 does not restrict osteophytes on the anterior or posterior margin of the vertebral body.

In addition to the long-term postoperative complications mentioned above, Nguyen et al. [56] conducted a literature search from January 2005 to August 2023 and stated that short-term postoperative complications were mainly related to surgical methods. These included dysphagia up to 70%, laryngeal nerve injury 0-1.25%, Horner syndrome 0.06%, hematoma 0.01%, and gross instrument compression 0.3%.

3.2.4. Indications and contraindications for artificial cervical disc replacement

ACDF surgery is a classic operation for the treatment of cervical degenerative diseases, and ACDR surgery is the innovation and development of ACDF surgery. Most patients suitable for ACDR surgery can also perform ACDF surgery. In terms of surgical indications, ACDF surgery is more extensive than ACDR surgery. In terms of surgical contraindications, ACDR surgery needs more attention than ACDF surgery [57].

At present, there is no uniform indication for ACDR surgery at home and abroad. McAfee [58] concluded that the indications of ACDR include: (1) The symptoms or signs of cervical radiculopathy and/or myelopathy require grade 1-3 surgical treatment, with or without axial neck pain. (2) Surgery at 1 to 3 segments from C3 to T1 is required and does not respond to any one or more of the following conservative treatments lasting at least 6 weeks: disc herniation with radiculopathy, spinal radiculopathy, disc herniation with myelopathy, or spinal myelopathy. (3) Focal compression lesions must be diagnosed by computed tomography, myelography, or magnetic resonance imaging. (4) The patient must have abnormal neurological signs that indicate radiculopathy or myelopathy: abnormal reflexes, sensations, or motor intensity identified in the dermatome or myotome. (5) Patients aged 18 to 65 years.

The contraindications of ACDR surgery summarized by McAfee [58] are as follows: (1) Rheumatoid arthritis, ankylosing spondylitis, ossification of posterior longitudinal ligament or diffuse idiopathic skeletal hyperplasia. (2) Insulin-dependent diabetes mellitus. (3) Patients with long-term steroid use or related diseases requiring long-term steroid use. (4) Pathological obesity. (5) Pregnant women. (6) Axial neck pain is the only symptom of the patient. Auerbach [59] et al. 's clinical studies on different artificial cervical disc prostheses are summarized. Contraindications also included metal allergy, small joint degeneration, severe cervical spine degeneration (intervertebral bridging, >50% drop in intervertebral height, >2° decrease in intervertebral motion), cervical spine instability, post-traumatic deformity, reoperation or adjacent segment surgery, osteoporosis or bone mass loss, malignancy and other systemic diseases, metabolic bone disease, etc. In addition to the above contraindications, the North American Spine Association (NASS) also lists ossification of the posterior longitudinal ligament and scoliosis as contraindications to ACDR [60].

In recent years, some clinical studies have found that there are unsatisfactory decompression, unsatisfactory symptom relief, spinal cord or nerve root injury, vertebral bone loss, neck pain, and periprosthesis ectopic ossification after ACDR. Therefore, through a series of clinical studies, clarifying the surgical indications of ACDR will help standardize the clinical application

of ACDR, improve the surgical efficacy and prognosis, reduce postoperative complications, and make ACDR mature and more perfect in the future.

4. Existing problems and future prospects

4.1. Existing problems

ACDR surgery is still facing many problems. First, there may be a risk of implant wear and displacement after ACDR. This may be due to the material and design of the artificial cervical disc and the individual differences of the patient. In the future, it is necessary to strengthen the research on artificial cervical disc materials to improve their biocompatibility and durability, and improve postoperative follow-up of patients to detect possible complications in time. The operation of ACDR is complicated, and the technical requirements of the surgeon are high. Therefore, it is necessary to further improve the standardization and standardization of surgical techniques to reduce surgical risks and improve surgical success rates.

Secondly, the selection of indications for ACDR surgery is also a problem that needs to be solved. At present, there is still some controversy and uncertainty about which patients are suitable for ACDR surgery. Therefore, it is necessary to further study the scope of indications for ACDR surgery in order to more accurately screen patients suitable for surgery and avoid unnecessary surgical risks.

4.2. Future prospects

With the continuous progress and innovation of technology, ACDR surgery is expected to be further improved and optimized. By utilizing advanced medical imaging technology, 3D printing technology, artificial intelligence and robot-assisted surgical systems, more precise surgical procedures can be achieved and more personalized treatment can be provided. In addition, the research and application of new biomaterials will also provide more possibilities for the design and manufacture of artificial cervical discs, making them closer to the physiological structure and function of natural cervical discs, improving their biocompatibility and durability, and reducing the risk of prosthesis related complications. Second, the scope of indications for ACDR surgery is expected to be clear and further expanded, allowing more patients to benefit. Finally, with the continuous expansion of the global medical market and the improvement of people's demand for health, the market prospect of ACDR surgery is also very broad. In the future, with the continuous optimization and allocation of medical resources, ACDR surgery is expected to be more widely used and promoted worldwide.

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