Recent Progress of Nanomaterials in Implants

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Abstract. With the continuous development of nanotechnology and the increasing emphasis on physical fitness, the age of onset of bone diseases is becoming younger and younger. Bone tissue engineering and artificial joint replacement surgery, with the application of bio-materials as implants, are considered as promising approaches to treat bone diseases. Among various bio-materials, Implants made of nanomaterials with appropriate biocompatibility and biomechanical properties can be used clinically to address some of the problems associated with bone disease. This paper reviews the use of nanoceramic and polymeric nanomaterials in implants, the use of some nanomaterials in bionic joint fluids for antibacterial lubrication of implants in the human body. Besides, the potential for nanomaterials in implants to cause some damage or injury to the respiratory system and other body tissues, and the prospects for the use of nanomaterials in implants in the future are also introduced. The aim is to raise awareness of the use of nanomaterials in implants and the importance of biocompatibility, biomechanical properties and antithrombotic properties for future implant applications.

Keywords: Nanotechnology, Nanomaterials, Implants.

1. Introduction

Nanotechnology can be used in a wide range of implants due to its nano effect, small size effect and quantum effect [1]. The incidence of osteoarthritis tends to increase with age. Common bone and joint diseases include rheumatoid arthritis, osteoarthritis and haemophilic arthritis. The most common osteoarthritis is osteoarthritis, also known as proliferative osteoarthritis or degenerative joint disease, which is more prevalent in women than in men, especially in older people over 65 years of age [2,3]. The clinical manifestations of osteoarthritis are stiffness, pain and impaired movement due to degeneration of the diseased joint [4]. Treatment of osteoarthrosis is conservative in the first instance, but surgery is an extremely effective treatment for joints that have developed more severe functional impairment. Among the surgical treatments, artificial joint replacement surgery is an extremely important surgical treatment for osteoarthrosis. In recent years, artificial hip replacements have become a more established clinical procedure, and knee replacements can also be used to relieve joint pain due to factors such as osteoarthritis of the knee. As a long-lasting implant, a replacement joint prosthesis should have good biocompatibility, biomechanical properties, good wear resistance and corrosion resistance. Nanomaterials such as nanometallic and nanoceramic materials are currently used in joint replacement surgery and have good biocompatibility and biomechanical properties.

The use of nanoceramics materials in dentistry and the use of nano-polymer materials in cartilage, tendons and ligaments is currently well established. There is also some research on the lubricating effect of joint lubricants made from nanomaterials in implants and on the antibacterial effect of nanomaterials such as nanosilver in implants. However, there is an overall lack of research on the side effects of nanomaterials in implants, whether as replacement joints, artificial ligaments, artificial tendons, as joint lubricants or as antibacterial agents. Future research into how nanomaterial implants can be more biocompatible, biomechanical and other properties would be of great interest.

2. Nanomaterials in implants

Nanomaterials are widely used in medical implants due to their surface and bulk effects, and their biocompatibility. Current nanomaterials, such as nanoceramics, nano metallics and nano polymers, can be used in different parts of the body for different purposes. For example, nano polymers can be

made into musculoskeletal tissue; nanoceramic materials are used to make artificial teeth, bones and joints; and nano metallic materials, such as titanium nanoparticles, are well-known and widely used in implants.

2.1. Nanoceramic materials

Nanoceramic materials are used as biomaterials in medical applications, have no toxicity or side effects and are biocompatible and corrosion-resistant. Currently, ceramic materials made from nanoceramic powders can effectively reduce surface defects. Fractures in ceramic materials are mainly caused by pores, coarse particles or cracks within the materials. the finer the raw material is, the stronger the ceramic material will be.

There are three types of nano-ceramic materials in common use today.

a) Ceramics that are almost biologically inert, such as aluminium oxide (Al_2O_3). These materials are of high mechanical strength, have a good colour and are simple to mould. They can be used to make fixed restorations such as anterior bridges and crowns and can be used in a wide range of clinical applications.

b) Surface-active biomaterials, such as dense hydroxyapatite with a high density, relatively low pore dispersion and small internal micropores. They can play a role in promoting the growth of bone tissue in the pores and be used mainly for artificial bone.

c) Resorbable biomaterials, such as tricalcium phosphate, which are mostly sintered or porous and have good biocompatibility, biodegradability. They are mostly used to make artificial bones, artificial tooth roots and bone replacement materials, etc.

2.2. Nano-polymer materials

Injuries to muscle or bone can heal within a few weeks after repositioning and fixation. When the defect in the bone cortex is large and cannot be bridged, it needs to be repaired with autologous, allogeneic or synthetic biomaterials. Currently, bones are usually repaired and reconstructed with calcium salts, polymers or porous metals. In the case of ligament or tendon injuries, it is crucial to align the severed ends and guide their regeneration. Most of this is currently achieved by using natural or synthetic polymeric materials. However, synthetic polymeric materials are currently less commonly used in clinical practice because synthetic ligaments have a shorter lifespan and are more prone to re-rupture and are less biocompatible. As a result, autologous ligaments are currently the most common surgical option. For cartilage, for example, injuries to the meniscus, the defect rarely regrows and therefore requires artificial or natural materials for filling.

The three nano polymeric materials currently used in implants are

a) Type I collagen fibres and hydroxyapatite, which is a laminated structure at the nanoscale with high tensile and compressive strength. By remodelling the bone tissue structure, the bone exhibits good plasticity to stress.

b) Type II collagen fibres, a structure that modulates the response of cartilage to tension and pressure. However, the limitations of this material are that it has a limited ability to adapt to changing stresses and to regenerate. Additionally, the survival of cartilage requires cyclic stress.

c) Type III collagen fibres, which are predominantly contained in the ligament and tendon matrix. They have good plasticity and can adapt to changes in stress and regeneration processes.

3. Nanomaterials in implants for lubrication and antimicrobial action

The joint cartilage and the synovial membrane secrete the joint fluid that allows the natural joint to maintain normal movement for periods. However, during the artificial joint implantation process, all of the articular cartilage and surrounding synovial tissue are removed, resulting in the natural joint lubrication system being broken and the joint no longer secreting joint fluid. Inadequate lubrication and the need to withstand high loads lead to more severe wear and tear of the artificial joint during use. This leads to inflammation of the joint, loosening of the joint prosthesis and fractures around the

prosthesis, which aggravate the physical and psychological suffering of the patient as well as the financial burden. As a result, the use of bionic lubricants injected into artificial joints to improve lubrication has been widely used in clinical practice.

Liang et al. used the relatively good adsorption properties of polydopamine nanoparticles (PDA) and the anti-wear and anti-friction effects of hyaluronic acid (HA) to prepare a bionic joint fluid and tested the tribological properties and biocompatibility of the prepared bionic joint fluid.

3.1. Friction reduction test

The results of the test were that both saline and HA solutions had large coefficients of friction. The lubrication effect of the HA joint injection solution, which is currently used in large quantities in clinical practice, is not very satisfactory. The coefficient of friction was significantly reduced with the addition of PDA, and good friction reduction performance was achieved at a low concentration of 5mg/ml of PDA [5]. The surface of PDA is smooth and spherical, and when the friction interface is in relative motion, PDA can change the original sliding friction into rolling friction, thus reducing the coefficient of friction in this way.

Comparing the experimental results, as shown in Fig.1, Fig.2 and Fig.3, it can be found that the experimental group with only PDA has a smaller coefficient of friction than the experimental group with HA+PDA at the same concentration. Therefore, Liang et al. considered that the reason for such results may be due to the fact that PDA adsorbed at the friction interface exerted a better boundary lubrication effect. In the presence of HA, there would be competition between HA and PDA for adsorption at the friction interface, resulting in weaker friction lubrication and higher friction coefficient. It can also be realised that the excellent a friction reduction performance of PDA is not related to the concentration of PDA contained in the lubricating fluid [5].

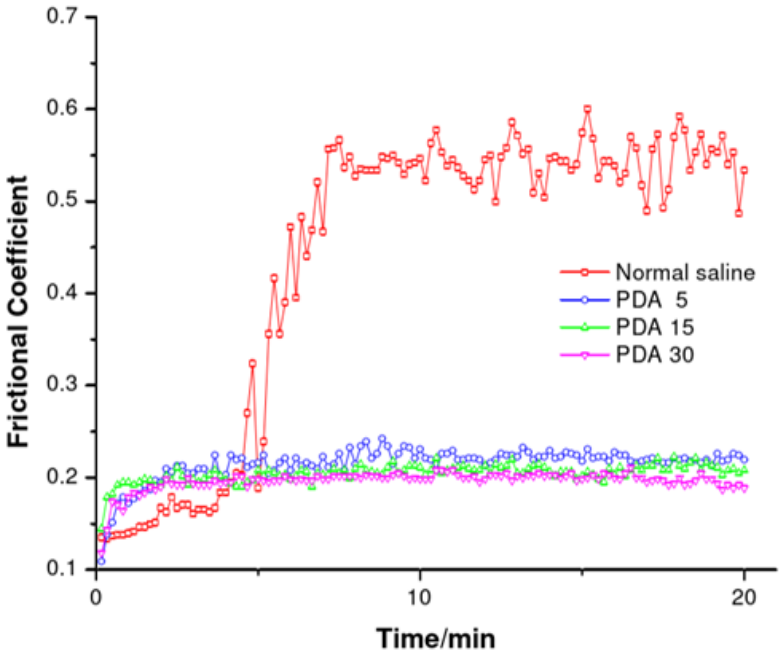


Figure 1. Friction coefficient of saline and different concentration of PDA changing with time under the load of 20N [5]

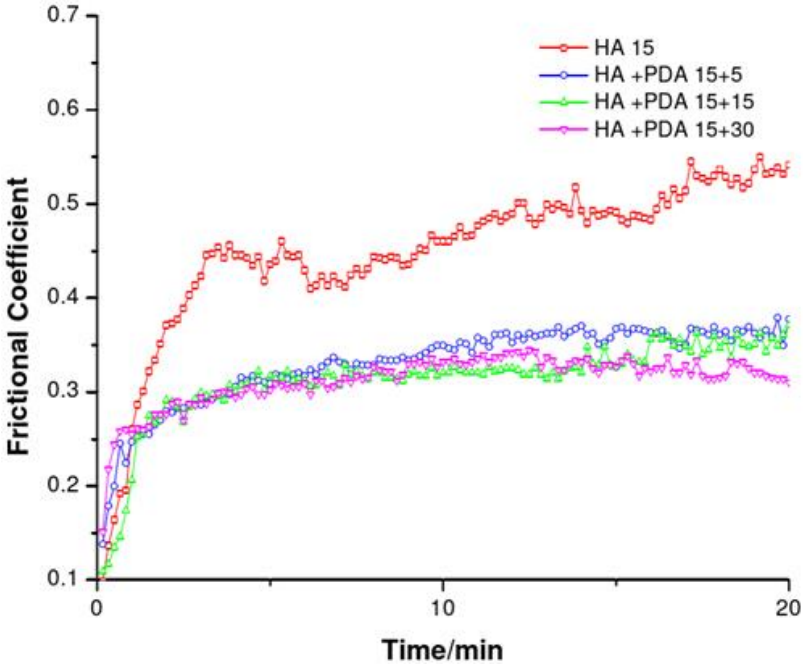


Figure 2. Friction coefficient of HA (15mg/ml) and HA containing of different concentrations of PDA changing with time under the load of 20N [5]

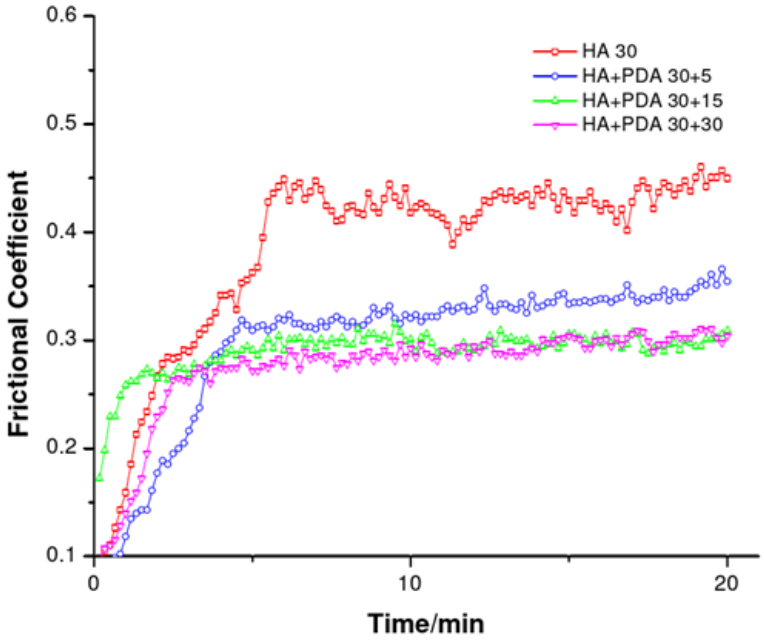


Figure 3. Friction coefficient of HA (30mg/ml) and HA containing of different concentrations of PDA changing with time under the load of 20N [5]

3.2. Evaluation of biocompatibility test results

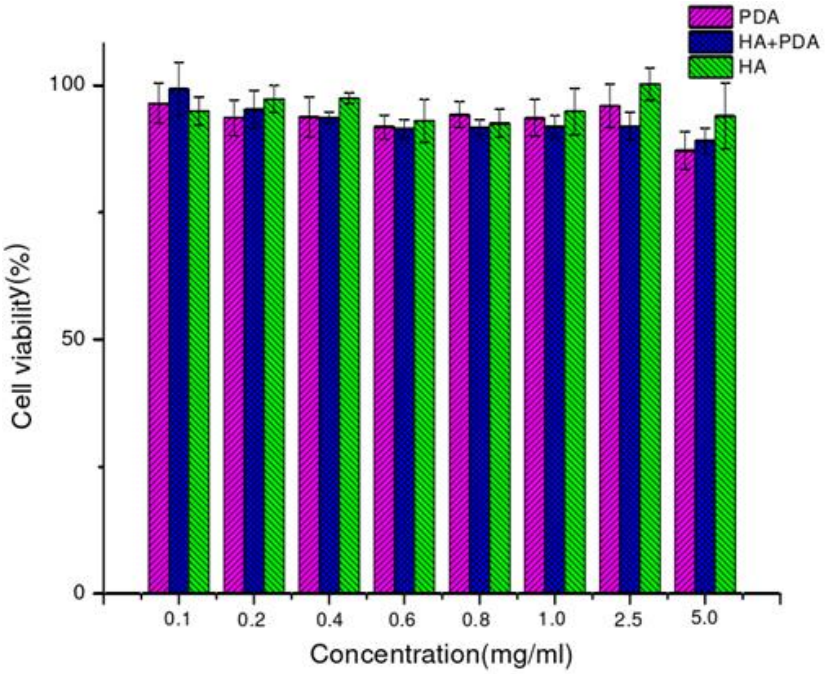


Figure 4. Cell viability of Ana-1 cells exposed to PDA, HA and HA with PDA [5]

The cytotoxicity of the configured release lubrication solution was tested on mouse macrophage Ana-1 cells in the logarithmic growth phase and cell viability was calculated. As shown in Fig.4, the results of the cytotoxicity assay are shown in the graph and it is concluded that the cell survival rate decreases slightly with increasing concentration of the medium, but the overall survival rate is above 90%. This indicates that the biocompatibility of the prepared bionic joint fluid is good and there is no significant cytotoxicity [5].

Other current nanomaterials used in implants for lubrication and antimicrobial effects are ZnO_2 and ZnO nanoparticles, which when added to lubricants can significantly improve the friction reduction and anti-wear capacity of the lubricant. There is also titanium dioxide-loaded silver nanohydroxyapatite/polyamide 66 (TiO_2-Ag-nHA/PA66) which can be used as a bone-filling material and is a good bone replacement material.

4. The shortcomings of nanomaterials in implants

Some of the disadvantages of nanomaterials are that some of them contain heavy metals, and the precipitation of heavy metal ions may have certain effects on the human liver, nervous system, immune system and even reproductive development.

4.1. Toxicity to the respiratory system

Kaewamatawong et al. conducted experiments on the toxicity of nano-silver to the respiratory system [6]. After 30 days of dripping nano-silver solution into the trachea of mice, it was found that the lung tissue of the mice showed reduced lung function and even acute inflammation. When rats were exposed to 18-19 nm silver nanoparticles for 98 days, the lung tissues showed alveolar thickening and various degrees of inflammation, which led to a decrease in lung function [7,8].

4.2. Toxicity to other tissues

A study using 2.5mg of nanosilver (15mm) and micron silver (2-3.5μm) in mice by gavage for 3 days found severe inflammatory damage to liver tissue and altered expression of 4 genes associated with this condition, thus demonstrating the toxic effects of nanosilver on the liver [9].

Liu Huanliang et alfound that nanosilver particles can cause cellular immune dysfunction [10]. Forty-two male mice were divided into three groups and injected with the toxin via a non-exposed tracheal drip method: low dose group: 3.5mg/kg of nanosilver, high dose group: 17.5mg/kg of nanosilver and control group: calf serum for 5 weeks. The results of the experiment showed that the spleen and thymus organ coefficients of the control rats did not change, while the body weight of the rats injected with nano silver decreased significantly ($P<0.05$), peripheral blood helper T cells decreased and cytotoxic T cells increased. Therefore, for the application of nanomaterials, people should pay attention to their biosafety. The current research on the biosafety of nano metallic particles has shown that some mechanisms of action or toxic effects of nano metallic particles cross or interact with each other. It is essential to find the corresponding control methods and detoxification methods to give priority to providing comprehensive safety evaluation information for clinical application.

5. Prospects of nanomaterials for orthopaedic applications

The application of nanomaterials in orthopaedics should mainly consider their biocompatibility, biomechanical properties and anti-thrombotic properties.

For nanomaterials containing heavy metal elements, attention should be paid to the impact of the precipitation of heavy metal ions on body tissues. In addition, in terms of nanomaterials such as artificial bones made of titanium, the abrasive debris produced by the friction between them and their own bones should be taken into account, for it can lead to the appearance of surrounding tissue hyperplasia and bone dissolution, so that patients also need to undergo revision surgery. There are two solutions to address these issues. The first is to find a more suitable material, and the second, is to adequately lubricate the joint prosthesis [5]. For bioceramic implants, the mechanical behaviour of the human skeletal system in different states of stress as well as the biomechanical aspects should be considered. The structural design and processing should also be studied according to the osteogenesis mechanism with the human skeleton and friction damage, etc., to adjust the structure of bioceramic implants and their composition, so that a more suitable nano-ceramic biomaterial can be developed for clinical application.

6. Conclusion

Nanomaterials are usually composed of small molecules or atomic units. Because of its nano effect, small size effect and quantum effect, nano materials can be used in implants and play a good role. This paper found that nano-ceramic materials are often used in dentistry, for example nano-Al_2O_3 is used to make fixed restorations such as crowns and bridges due to its simplicity and near bio-inertness. Nano-polymer materials are used to make artificial ligaments, tendons and cartilage, which do not easily regenerate or even regenerate after damage, to give stability and mobility to the patient's joints to sustain daily activities or even sports. Nanomaterials can also be used in the post-arthroplasty lubrication fluid to replace the tissue fluid, thus reducing friction between the replacement joint and the patient's own joint, which can lead to friction between the replacement joint and the patient's own joint due to a reduction in tissue fluid secretion after joint replacement surgery. However, due to the presence of heavy metals in some nanomaterials, the precipitation of heavy metal ions can cause damage to the respiratory system or other body tissues. Future research into the use of nanomaterials in implants should focus on their biocompatibility, biomechanical properties and the need for materials with good wear and corrosion resistance so that they can be better used in clinical practice and provide a better surgical solution for patients with arthrosis as soon as possible.

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