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E-mail: jzus_b@zju.edu.cn

Correspondence

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Application of custom-made joint prostheses in wrist

Xiaodi ZOU[1,2], Yanzhao DONG[1], Changxin WANG[2], Hui LU[1]✉

[1]*Department of Orthopedics, The First Affiliated Hospital, Zhejiang University, #79 Qingchun Road, Hangzhou 310003, China*
[2]*Department of Orthopedics, The Second Affiliated Hospital of Zhejiang Chinese Medical University, Xinhua Hospital of Zhejiang Province, #318 Chaowang Road, Hangzhou 310000, China*

Abstract: Wrist diseases and injuries severely affect individual's daily life and work. Traditional wrist surgeries often use standardized joint prostheses, but these prostheses may not fully accommodate individual's anatomic structure and functional needs. In recent years, with the development of 3D printing and computer-aided design, the application of customed joint prostheses in wrist has gradually attracted attention. This article critically examines the advancements and applications of custom-made joint prostheses in wrist surgery, while also addressing the potential benefits and challenges they present.

Key words: Custom-made prosthesis, 3D-Printed prosthesis, Arthroplasty, Prosthetic advancement, 3D Printing technology.

Dear editor

The wrist joint is a highly mobile functional joint. Wrist conditions including traumatic and degenerative arthritis, rheumatoid arthritis, and giant cell tumors of the distal radius, cause significant pain and mobility impairment. In joint surgery, the decision to use joint prostheses to reconstruct joint function is greatly influenced by the characteristics of the prosthesis (Mok et al., 2016). However, traditional implants have limitations such as shape mismatch, inadequate implant-bone interface strength which causes loosening, and poor bone ingrowth (Zhang et al., 2014).

Three-dimensional (3D) printing offers solutions through customized designs and porous structures for bone in growth and stability (Chikarakara et al., 2014). Compared to conventional customized prostheses, 3D-printed prostheses have a shortened one-week manufacturing cycle. Three-dimensional printing allows for patient-specific implants with advantages over generic options (Tredan et al., 2022). It facilitates surgical planning with accurate 3D models that reflect the unique characteristics of a patient's underlying anatomical disease. As part of sophisticated modern surgical planning, the advantages of employing such modern technology empower orthopedic surgeons to predetermine the dimensions of a precise resection and simulate surgical maneuvers(Hoang et al., 2016). However, there is currently limited literature on customized prosthetics, and further research is needed to assess their long-term clinical efficacy. Furthermore, the new generation of wrist prostheses requires constant improvement to reduce complications and enhance long-term survival rates.

✉ Hui LU, huilu@zju.edu.cn
Xiaodi ZOU, zxd261314@163.com
Hui LU, https://orcid.org/0000-0002-5921-1043
Xiaodi ZOU, https://orcid.org/0009-0009-0071-9203

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The Swanson prosthesis is a first-generation prosthesis made of silicone gel, designed to restore mobility and function of the wrist joint (Summers and Hubbard, 1984). Its hinged design allows for flexion and extension movements similar to a native wrist joint, but it is susceptible to aging and damage, leading to postoperative complications like silicone synovitis and prosthesis fracture. Second-generation prostheses, such as the Volz and Meuli prostheses, feature proximal and distal anchor-shaped structures securely fixed within the metacarpal and radius bones. However, these prostheses have mechanical deficiencies, that can result in joint dislocation and prosthesis deformation. Researchers have enhanced the prosthesis design over the years, drawing inspiration from the Meuli prosthesis and, leading to the creation of the MWP III prosthesis (Dennis et al., 1986). Third-generation prostheses, including the Trispherical, Biaxial, and MWP III prostheses, were developed to better accommodate the biomechanical characteristics of the human wrist joint. These prostheses aim to restore the radial inclination angle and palmar tilt angle of the wrist joint by adopting an offset placement closely resembling normal anatomy. However, the fixation technique used in these prostheses is not significantly improved over predecessors, and issues like long-term prosthesis loosening and sinking persist(Shao et al., 2023).Fourth-generation wrist prostheses, such as the Universal series (type I and II), RE-MOTION, and Maestro prostheses, have improved material composition and fixation. The proximal and distal ends are predominantly cobalt-chrome-molybdenum and titanium alloys, while the joint surface is semi-circular ultra-high molecular weight polyethylene. The fixation method involves inserting the distal end into the third metacarpal medullary cavity, then using screws to secure the partial wrist and metacarpal bones on both sides. The Universal II prosthesis is extensively used (Gislason et al., 2017), because it has a modified distal fixation and expanded radial component. However, it experiences higher dorsal and ulnar loads than palmar and radial loads. The RE-MOTION prosthesis resembles the Universal II but has a press-fit fixation to the carpal component, offering greater flexibility. The Maestro prosthesis uses titanium alloy carpal and radial stems, a cobalt-chromium alloy joint body, and an ultra-high molecular weight polyethylene joint ball. Over a period of 8 years, the Maestro prosthesis had a 95% survival rate, as well as offering pain relief, and motion improvements.

The latest generation of prostheses has reduced the likelihood of loosening and periprosthetic fracture, but conventional prostheses still risk complications from inadequate alignment between the wrist joint prosthesis and the patien’s bones. Wrist implants have not achieved the 10-year survival rates of knee (96.1%) and hip (95.6%) implants(Mok, et al., 2016) . Contemporary prosthetic design and materials enable the production of more personalized prostheses tailored to individual needs. Traditionally customized prostheses had drawbacks like high costs and long manufacturing times. However, 3D printing technology has ameliorated these limitations. A retrospective study [8] comparing two cohorts of patients who underwent en bloc resection of Campanacci grade III or recurrent giant cell tumors of the distal radius, reconstructed with either a 3D printed prosthesis (L-P) or osteoarticular allograft (FA), found that the combined use of LARS® and 3D-printed prostheses produced better postoperative clinical, functional, and radiological outcomes in the L-P group. Both techniques significantly improved postoperative function over a mean 40.42 ± 18.43-month follow-up. In a 10-year follow-up study of a 36-year-old with a distal radius giant cell tumor treated with a custom wrist prosthesis, Damert et al (Damert et al., 2020). found approximately 10 mm subsidence of the radial component and 15° increased radial abduction. Comparing 30 distal radius giant cell tumor reconstructions, Wang et al(Wang et al., 2020). found improved motion, strength, and function with both 3D-printed prostheses and osteoarticular allografts, but prostheses showed significantly greater extension, flexion, and functional scores. Allograft complications were more frequent, including infection, resorption, fracture, and arthritis, while prosthetic complications were less frequent, mainly subluxation and dissociation, without arthritis.

Personalization of prosthetics through 3D printing technology maximizes restoration of the wrist's biomechanical features, reducing prosthesis pressure on the osteotomy plane and minimizing issues like sinking and loosening. Arthroplasty effectively alleviates wrist discomfort while maintaining optimal mobility, but wrist prostheses still do not match the long-term survival rate of knee or hip replacements. In summary, 3D printed prostheses have recently shown promise, with manufacturing advances potentially enabling better patient outcomes. However, there is currently limited long-term clinical data on custom wrist prostheses. More research is needed to evaluate long-term outcomes and complications. Additionally, the occurrence of corrosion is one of the challenges of metal implants (Kia et al., 2022). Upon contact with tissue, metal ions are rapidly released into the body, leading to restricted oxygen diffusion and resulting in heightened toxicity levels. Consequently, there can be adverse effects on cellular function (Mitra et al., 2021). The increasing demand for metallic implants is putting pressure on researchers to improve the materials and techniques to meet the requirements. Therefore, scientists have initiated investigations into various enhancement approaches aimed at augmenting the osteogenic capacity, osteoconductivity, bacterial inhibition, and biocompatibility of bone implants (Pinheiro et al., 2022; Li et al., 2024).

Sincerely,
Hui LU

Data availability statement

Not applicable.

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Author contributions

Hui LU designed the study; Xiaodi ZOU drafted the manuscript, Yanzhao DONG performed literature selection; Changxin WANG revised the manuscript. The authors have read and approved the final manuscript.

Compliance with ethics guidelines

The authors declare that they have no conflict of interest.

All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5). Informed consent was obtained from all patients for being included in the study. Additional informed consent was obtained from all patients for whom identifying information is included in this article.

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