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Treatment of Periprosthetic Femoral Fractures and Prospects

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Abstract

Periprosthetic fracture of femur is a common and complex complication after joint replacement. With the increase of operation volume, its incidence is increasing year by year. The treatment of this fracture is affected by many factors, including fracture type, prosthesis stability, patient age and comorbidities, and individualized treatment strategy is needed. In recent years, the internal fixation technology and prosthetic revision technology have made significant progress in surgical treatment, such as locking steel plate, titanium cable and bridge combined internal fixation system and other new technologies have effectively improved the treatment effect. In addition, the application of new materials and 3D printing technology, as well as the optimization of multidisciplinary cooperation mode, also provide new ideas for the treatment of complex fractures. However, there are still some problems such as inaccurate diagnosis, difficult choice of treatment options and high incidence of postoperative complications. In the future, technological innovation, the introduction of artificial intelligence and big data, and the further development of personalized treatment will bring more possibilities to improve the prognosis and quality of life of patients. This study summarizes the relevant research results and prospects the future development direction, providing references for clinical practice and subsequent research.

Keywords

Periprosthetic Fracture of Femur, Treatment Progress, Research Prospects

1. Introduction

Periprosthetic femoral fractures (PFF) is a common serious complication after

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joint replacement. Its incidence increases year by year with the acceleration of the global aging process and the increase in the number of artificial joint replacement. The occurrence of PFF not only significantly reduces the quality of life of patients, but also increases the medical burden and the risk of postoperative complications. The Vancouver classification system, which is widely used in clinic, provides important guidance for the classification and treatment of PFF, but it still has limitations in the treatment of complex fractures (such as B2 and B3), such as the lack of consistency in the evaluation of prosthesis loosening and bone bed defects. Although significant progress has been made in conservative treatment and surgical treatment (including internal fixation technology and prosthetic revision Technology) in recent years, the applicability and long-term effect of different treatment options are still controversial. In addition, the biomechanical properties of existing fixation materials (such as locking plates, titanium cables and combined internal fixation systems) have not been fully evaluated, and the application potential of new materials and technologies (such as 3D printing and bioactive materials) has not been systematically explored. At the same time, the management of postoperative complications (such as infection, nonunion and prosthesis loosening again) is still facing challenges, and it is urgent to optimize the postoperative rehabilitation intervention strategy. In this context, this paper attempts to systematically review the existing research, clarify the key issues that have not yet been solved in PFF management, focus on the surgical treatment of Vancouver type B fracture and the application potential of new technology, and provide theoretical support and clinical reference for classification optimization, treatment improvement and patient prognosis improvement.

2. Classification and Evaluation of Periprosthetic Femoral Fractures

2.1. Vancouver Classification System

2.1.1. Classification Criteria

Vancouver classification system is a classification standard widely used in clinical practice for femoral periprosthetic fractures. It was proposed by Duncan and Haddad in 1995. It is mainly classified according to fracture location, prosthesis stability and bone bed quality. According to the classification criteria, femoral periprosthetic fractures are divided into three main types: type A, type B, and type C. Among them, type a fractures are located above the prosthesis or in the greater trochanter and lesser trochanter regions; Type B fractures occur around the prosthesis and are further divided into B1 (stable prosthesis, good bone bed), B2 (unstable prosthesis, good bone bed) and B3 (unstable prosthesis, poor bone bed) according to the stability of the prosthesis and the condition of the bone bed; Type C fractures are located distal to the prosthesis. Zhu Lingqi *et al.* (2023) pointed out that the proposal of Vancouver classification system provided a clear basis for the standardized diagnosis and treatment strategy selection of fracture types [1]. Huang Jun and Peng Hao (2022) also emphasized that the accuracy of the classification system depends on preoperative imaging evaluation, including X-ray, CT and MRI examinations [2]. This system has become the basis for guiding treatment decisions, but the classification accuracy and clinical implementation are still limited by the subjectivity of image evaluation.

2.1.2. Clinical Application and Limitations

Vancouver classification system is widely used in clinical practice to evaluate the treatment of periprosthetic femoral fractures. However, it also has some limitations in practical use. Müller analyzed the effect of the system in the treatment of patients with periprosthetic fractures through a retrospective study, and pointed out that it has a significant guiding role in the treatment of fractures, especially when determining the surgical method and prosthesis treatment [3]. However, the study of Iwata showed that the system has certain limitations in dealing with complex fractures, such as the comprehensive evaluation of prosthesis instability and severe bone bed defects in B3 fractures is more difficult [4]. In addition, Haraguchi pointed out through a case study that some cases of occult fractures or concomitant injuries in other parts may not be fully included in the Vancouver classification [5]. In general, although the Vancouver classification system is the current clinical standard, its applicability in imaging dependent and complex fracture situations still needs to be further optimized and supplemented to more comprehensively adapt to diverse clinical needs.

2.2. Evaluation and Diagnosis of Fracture

The evaluation and diagnosis of periprosthetic fracture of femur is the key link to determine the treatment plan, which mainly includes clinical evaluation and imaging examination. Lamb analyzed the data from the British National Joint Registry database and pointed out that the fracture type, bone condition and prosthesis stability of patients were the key factors affecting the treatment effect. The clinical evaluation should be combined with the patient's past medical history, pain degree and functional limitations. Imaging examination plays an irreplaceable role in the diagnosis of fracture. Commonly used methods include X-ray, CT and MRI [6]. Han found through biomechanical research that imaging examination can not only clarify the fracture type, but also evaluate the mechanical status of internal fixation and prosthesis, which is essential for the formulation of surgical plan [7].

In addition, podlong research pointed out that the new three-dimensional reconstruction imaging technology can more intuitively display the spatial position of the fracture and bone loss, and provide a more accurate reference for the preoperative planning of complex fractures [8]. However, the results of imaging examination need to be comprehensively analyzed in combination with clinical evaluation to avoid misdiagnosis or missed diagnosis. Overall, comprehensive fracture evaluation and accurate diagnosis are the basis for formulating personalized treatment plans, which requires the organic combination of multiple evaluation methods.

3. Research Progress of Treatment Options

3.1. Surgical Treatment of Vancouver Type B Fracture

Vancouver type B fracture is one of the most challenging types of periprosthetic fractures of the femur. According to the stability of the prosthesis and the quality of the bone bed, it is further divided into three subtypes: B1, B2 and B3. The choice of treatment depends not only on the type of fracture, but also on the patient's age, bone condition and previous operation history. Due to the high complexity and diversity of type B fractures, the optimization and standardization of treatment methods are still controversial.

(1) Type B1 fracture: stable prosthesis

Because the prosthesis is stable and the bone bed is good, type B1 fractures are usually treated with internal fixation technology. Qiu Fuping studied the effect of locking plate combined with titanium cable technology in the treatment of type B1 fractures, and the results showed that this method can provide good fixation strength, and at the same time, it has less damage to the surrounding soft tissue, which is helpful for the early healing of fractures [9]. However, the application of locking plate may lead to stress concentration in adjacent parts, thereby increasing the risk of re-fracture, which is worthy of further discussion.

(2) Type B2 fracture: prosthesis instability

For type B2 fractures with unstable prosthesis, prosthetic revision is the preferred option. Zhang Hanpeng studied the application of biological long stem femoral prosthesis, and the results showed that the long stem prosthesis can effectively improve the stability of the prosthesis by optimizing the stress distribution and increasing the fixation area [10]. However, this method has high requirements for bone bed quality, especially in patients with osteolysis, which needs to be combined with bone graft technology to improve bone bed support. In addition, through the analysis of the curative effect of Vancouver B2 and B3 fractures, Maihemuti emphasized that conservative treatment could not effectively solve the problems of prosthesis loosening and bone bed injury, which may lead to further deterioration of the disease [11]. This study highlighted the importance of prosthetic revision in type B2 fractures, but also showed that the risk of postoperative infection and prosthesis re loosening still need attention.

(3) Type B3 fracture: unstable prosthesis and poor bone bed quality

Type B3 fractures are considered to be one of the most complex types due to poor bone bed quality and prosthesis loosening. Xu Yi discussed the therapeutic effect of double allogeneic cortical bone plate "internal splint" support combined with embracing device fixation, and found that this technology has significant advantages in reconstructing bone bed and enhancing the stability of prosthesis [12]. However, its postoperative infection rate is high, and the requirement for surgical experience is high. The safety and effectiveness of this method in different patient groups need to be further evaluated. In addition, Chen Zhijiang studied the application of open reduction with titanium cable locking plate technology in complex fractures, and found that this technology can not only rebuild the fracture stability, but also effectively protect the periprosthetic bone, especially in patients with Vancouver B3 fracture, significantly reducing the incidence of postoperative complications [13]. The study also pointed out that by optimizing the fixation technology, early weight-bearing rehabilitation became possible, thus further improving the functional prognosis of patients. The treatment strategies and application scope of different subtypes of Vancouver B fracture are shown in **Table 1**.

Table 1. Treatment strategies and application scope of different subtypes of Vancouver B fracture.

Fracture type	Treatment strategy	Advantages	Limitations	Scope of application
Type B1	Internal fixation technology	Provide good fixation strength; Less damage to soft tissue	Increased risk of adjacent fractures; Stress concentration may affect long-term stability	The prosthesis was stable and the bone bed was of good quality
Type B2	Prosthetic revision Technology	Optimize the stress distribution; Enhance prosthesis stability	High cost; Higher risk of postoperative infection	The prosthesis was unstable and the bone bed was of good quality
Type B3	Prosthetic revision & bone grafting	Reconstruction of bone bed; Reduce the risk of re-fracture	Complex technology; High incidence of postoperative complications	Unstable prosthesis and poor bone bed quality

3.2. Research Disputes and Unanswered Questions

Although significant progress has been made in the surgical treatment of Vancouver B fracture at the technical level, the following key controversies and unanswered questions still exist:

First, the applicability of the existing classification system in dealing with complex PFF (especially B3 fractures) is still controversial. For example, in the case of severe bone bed defects and prosthesis loosening, the ambiguity of classification criteria may affect treatment decisions. Future research needs to explore more refined and comprehensive classification methods, and optimize them in combination with individual characteristics of patients.

Second, there are still disputes about the scope of application of conservative treatment and surgical treatment. For example, the study of Maihemuti showed that the curative effect of conservative treatment in B2 and B3 fractures is limited, but whether there are special cases of applicability in elderly patients or patients with multiple comorbidities still needs to be verified. In addition, the long-term effect comparison of different surgical methods (such as locking plate and prosthesis revision) has not been clear.

Third, there is a lack of systematic evaluation of the biomechanical properties and long-term effects of different fixation materials, such as locking plates, titanium cables and composite fixation systems. The practical application effect of new fixed materials (such as bioactive materials and 3D printing technology) also needs further exploration.

Fourth, the high incidence of postoperative infection, bone nonunion and prosthesis loosening again is still a challenge in clinical management. How to reduce these risks through preoperative evaluation, optimization of surgical techniques and early rehabilitation intervention is an important direction of future research.

4. Influencing Factors of Treatment Effect

4.1. Fracture Type and Severity

The type and severity of fracture play a decisive role in the treatment of femoral periprosthetic fracture (PFF). However, there are some controversies on the treatment effect of different types of fractures in the existing studies.

Qin Jing pointed out through the finite element analysis and clinical research of Vancouver type B fracture that the prosthesis stability of type B1 fracture is good, and generally internal fixation technology can be used to achieve satisfactory mechanical support and fracture healing [14]. The advantage of this study is the combination of biomechanical modeling and clinical data, with high scientific rigor. However, its limitation is that the performance differences of different fixation materials (such as titanium cable and locking plate) are not discussed in depth, which may affect the treatment choice for patients with complex fracture types or osteoporosis.

On the other hand, when studying the surgical treatment of B3 fracture, Xu Yiwen found that the double allogeneic cortical bone plate "internal splint" combined with embracing device fixation technology performed well in enhancing the stability of the prosthesis and reconstructing the bone bed. Although this technique effectively reduces the incidence of fracture nonunion, it has a higher risk of postoperative infection, especially in patients with severe bone bed defects who show the possibility of fixation failure. Compared with Qin Jing's study, Xu Yiwen's study pays more attention to complex cases, but its conclusion is still limited by the small sample size and the lack of long-term follow-up data.

4.2. Patient Age and Comorbidities

Patient age and comorbidities are important factors affecting the therapeutic effect of PFF, but the conclusions of studies in this field are not completely consistent.

Zhu Meng's retrospective analysis of elderly patients with PFF after total knee arthroplasty showed that elderly patients often increased the risk of postoperative complications due to osteoporosis and a variety of comorbidities [15]. The study also developed a risk prediction model based on multivariate analysis to evaluate the probability of postoperative infection and internal fixation failure. However, the deficiency of this study is that the specific impact of different comorbidities (such as diabetes or cardiovascular disease) on postoperative recovery is not clear, which limits the accuracy of the prediction model in clinical application.

In contrast, lamb pointed out through a large-scale database study that the postoperative mortality of elderly patients is closely related to fracture type and prosthesis stability. The advantages of this study lie in its large sample size and authoritative data sources, but its analysis of the interaction of multiple factors is insufficient, for example, the interaction between osteoporosis severity and prosthesis design is not considered. This leads to limitations in the applicability of conclusions in specific patient groups.

These two studies revealed the complexity of PFF management in elderly patients, but there is still a lack of consensus on how to optimize the surgical protocol to cope with age-related risks.

4.3. Prosthesis Design and Implantation Time

Prosthesis design and implantation time play a key role in the curative effect of fracture treatment. Wang Yingbiao found that the design of the prosthesis directly affects the mechanical stability of the fracture area by studying the application of the bridging combined internal fixation system in the treatment of periprosthetic fractures [16]. Especially for the long stem prosthesis, its optimized stress distribution can effectively reduce the stress concentration around the prosthesis, thus reducing the incidence of re fracture and prosthesis loosening. In addition, the study also pointed out that the longer the implant time, the greater the possibility of periprosthetic bone loss and osteolysis, increasing the risk of fracture. Therefore, when formulating the treatment plan, it is necessary to comprehensively consider the status and use time of the prosthesis, and give priority to the prosthesis design that can improve the biomechanical stability.

4.4. Surgical Technique and Fixation Material Selection

The choice of surgical techniques and fixation materials directly affects the therapeutic effect of PFF. Although the existing studies have put forward a variety of suggestions on the performance and applicability of fixed materials, the conclusions are not uniform.

Panrunan studied the application of closed reduction and minimally invasive locking plate internal fixation technology in elderly patients with type B1 fracture. The results showed that this technology can provide sufficient fixation strength while reducing intraoperative trauma, and significantly shorten the postoperative recovery time [17]. However, Han found through biomechanical experiments that the lack of stress distribution of locking plate may lead to an increased risk of adjacent fractures. This conclusion is particularly important for the elderly patient group, because osteoporosis may exacerbate this problem.

In addition, Zhang Hanpeng proposed the use of biological long stem prosthesis to optimize the stress distribution and effectively improve the stability of the prosthesis in the prosthetic revision technology. However, compared with internal fixation technology, prosthetic revision has higher cost and higher technical requirements for the surgical team. This makes prosthetic revision difficult to promote in the medical environment with limited resources.

5. Future Research Directions and Prospects

5.1. Comprehensive Analysis and Management Ideas of Existing Research

The existing research on femoral periprosthetic fracture (PFF) has made important progress in classification system, treatment strategy and postoperative management, but there are still significant limitations. Although Vancouver classification system is widely used, it has shortcomings in the evaluation of complex fractures such as B3 type, especially in the comprehensive analysis of prosthesis loosening and bone bed defects, which limits the ability of clinicians to formulate precise treatment plans. In terms of treatment strategies, internal fixation technology has shown good efficacy in patients with stable prostheses, while prosthetic revision is more suitable for cases with loose prostheses or severe bone bed defects. However, different studies have different conclusions on treatment selection, which is partly due to the different patient groups, sample sizes and follow-up time, which leads to the low universality of the results [18]. Postoperative management is another area that needs to be improved. Although the application of new fixation materials and surgical techniques has reduced complications to some extent, elderly patients and patients with osteoporosis are still high-risk groups of infection, nonunion and prosthesis loosening again. Current research shows that PFF management needs to further refine classification, optimize treatment decisions, and solve the shortcomings of existing research through multidisciplinary collaboration and the introduction of innovative technologies, so as to provide patients with more precise and efficient treatment.

5.2. New Insights into PFF Management

In the field of PFF management, the proposal of new insights needs to be based on the limitations of existing research, while paying attention to the combination of technological innovation and clinical practical needs. Personalized treatment should be taken as the core concept of management. According to the stability of prosthesis, bone bed conditions and general health status of patients, it is particularly important to dynamically adjust the treatment plan, especially in elderly patients, to optimize the safety and effect of treatment [19]. 3D printing technology provides a broad application prospect for PFF management. It can design personalized prostheses according to the patients' bone anatomical characteristics, showing significant advantages in the treatment of complex fractures and severe bone bed defects. Artificial intelligence and big data technology provide important support for diagnosis and treatment optimization. For example, the classification accuracy of Vancouver classification system is improved through intelligent algorithm, and data-driven auxiliary decision-making is provided for preoperative planning and postoperative monitoring.

5.3. Key Directions of Future Research

Future PFF research should focus on optimizing the classification system, promoting technological innovation and implementing personalized management to solve key problems in existing research. The limitations of Vancouver classification system require more accurate and dynamic typing tools. By integrating three-dimensional imaging technology and patient bone evaluation, its applicability in complex fractures can be improved, and the correlation between classification and treatment options can be improved [20]. The innovation of fixation materials and surgical technology is still an important direction of research. The potential of new bioactive materials and 3D printed prostheses in improving fixation strength and biocompatibility is worth further exploration. At the same time, it needs to verify its long-term effect and safety through multicenter randomized controlled trials. The combination of artificial intelligence and big data technology will promote the intelligent development of PFF management, optimize treatment options and risk assessment through predictive models, and provide data support for clinicians to improve decision-making efficiency. In addition, personalized treatment strategies for elderly and osteoporotic patients need more comprehensive research. From preoperative evaluation to postoperative rehabilitation, the whole process optimization will become the key to improve the success rate of treatment and reduce complications.

6. Conclusion

Periprosthetic fracture of femur is a complex and challenging orthopedic problem, and its treatment plan should be formulated comprehensively according to the fracture type, prosthesis stability and individual situation of patients. By reviewing the existing research, this paper summarizes the application and limitations of Vancouver classification system, and analyzes the technical progress of conservative treatment and surgical treatment, including internal fixation technology, prosthesis revision and the treatment of special types of fractures. At the same time, the key factors affecting the treatment effect, such as fracture type, patient age and prosthesis design, have also been discussed in depth. Looking forward to the future, technological innovation, new materials and multidisciplinary collaboration will provide important support for the optimization of treatment options and the improvement of patient prognosis. Continuous research and clinical practice will promote the treatment of periprosthetic femoral fractures towards precision and personalization.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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